REPORT 35

SWEEP

SOIL AND WATER

ENVIRONMENTAL

ENHANCEMENT PROGRAM

PAMPA

PROGRAMME D'AMÉLIORATION

DU MILIEU PÉDOLOGIQUE

ET AQUATIQUE

Canada

Ontario

SWEEP

is a $30 million federal-provincial agreement, announced May 8, 1986, designed to improve soil and water quality in southwestern Ontario over the next five years.

PAMPA

est une entente fédérale-provinciale de 30 millions de dollars, annoncée le 8 mai 1986, et destinée à améliorer la qualité du sol et de l'eau dans le Sud-ouest de l'Ontario.

PURPOSES

There are two interrelated purposes to the program; first, to reduce phosphorus loadings in the Lake Erie basin from cropland run-off; and second, to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion that contributes to water pollution.

SES BUTS

Les deux buts de PAMPA sont: en premier lieu de réduire de 200 tonnes par an d'ici 1990 le déversement dans le lac Erie de phosphore provenant des terres agricoles, et de maintenir ou d'accroître la productivité agricole du Sud-ouest de l'Ontario, en réduisant ou en empêchant l'érosion et la dégradation du sol.

BACKGROUND

The Canada-U.S. Great Lakes Water Quality Agreement called for phosphorus reductions in the Lake Erie basin of 2000 tonnes per year. SWEEP is part of the Canadian agreement, calling for reductions of 300 tonnes per year — 200 from croplands and 100 from industrial and municipal sources.

SES GRANDES LIGNES

L'entente entre le Canada et les États-Unis sur la qualité de l'eau des Grands Lacs prévoyait de réduire de 2 000 tonnes par an la pollution due au phosphore dans le bassin du lac Erie. PAMPA fait partie de cette entente qui réduira cette pollution de 300 tonnes par an — 200 tonnes provenant des terres agricoles et 100 tonnes provenant de sources industrielles et municipales.

100-05261/

TECHNOLOGY EVALUATION AND DEVELOPMENT SUB-PROGRAM

NUTRIENT DISTRIBUTION AND STRATIFICATION RESULTING FROM CONSERVATION FARMING

FINAL REPORT

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Prepared by:	ECOLOGISTICS LIMITED Waterloo, Ontario
Under the Direction of:	ECOLOGICAL SERVICES FOR PLANNING LIMITED, Guelph, Ontario - Subprogram Manager For TED
On Behalf of:	AGRICULTURE CANADA RESEARCH STATION, HARROW, ONTARIO N0R 1G0

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EXECUTIVE SUMMARY

Under conservation tillage systems using broadcast placement of phosphorus (P) fertilizers, there is a tendency for phosphorus to remain at or near the surface of the soil, resulting in vertical stratification. Band placement of P fertilizer in soils under conservation tillage may also lead to stratification of nutrients in a horizontal dimension.

In order to study the extent and severity of nutrient stratification in Ontario soils, a survey was conducted of the distribution of P and other nutrients, such as, Potassium (K), Magnesium (Mg) and Calcium (Ca) in a vertical and horizontal grid over a number of field conditions and management histories. The distribution of pH and organic matter and several soil physical properties (bulk density, cone penetrometer resistance, surface water infiltration) were also studied in relation to the distribution patterns of nutrients in the soil.

In the first of two experiments, a study of vertical stratification of nutrients, the effects of conservation tillage were compared with the effects of conventional tillage over a range of soil textural groups. At each of 36 sites, the soil was sampled at 2 cm increments to a depth of 20 cm, and below that at 5 cm increments to a depth of 45 cm. Samples were analyzed for plant-available P, K, Mg and Ca in addition to pH and organic matter. Soil physical property data (bulk density, cone penetrometer resistance and surface water infiltration) were also collected at each site.

A questionnaire was given to each farm cooperator requesting information regarding management history of the field. Based upon this information, the management of each field was classified as conventional tillage (CT), reduced tillage (RT) or notill (NT).

Nutrient data were grouped into three strata (0-10 cm, 10-20 cm and 20-45 cm) corresponding to expected average depths of secondary and primary tillage. The data within these strata were statistically summarized to determine means and regressed to find the slope over depth. The slope provided a relative index of change in nutrient concentration with depth and thereby an indication of stratification. The slopes of nutrient concentrations were analyzed for differences among tillage methods and soil types (clay, loam, sand). The stratum means of the measured soil physical properties and the gradient slope of organic matter were incorporated into the analyses. Questionnaire data were also included when possible.

Tillage systems had a significant effect on the vertical distribution of nutrients in the soil sampling layer. Soil under CT practices displayed a relatively even distribution of nutrients within the plough layer as indicated by a slower decline in nutrient concentrations with depth. Soil in fields managed under NT systems had a significantly greater rate of decline in nutrient concentration with depth. The lack of soil mixing resulted in an accumulation of nutrients at or near the soil surface. Soil organic matter content was similarly stratified with depth under NT conditions.

Soil texture was also a significant factor affecting the stratification of nutrients. Higher water infiltration rates associated with sandy soil enhanced the leaching of nutrients from the soil surface and reduced the development of a stratified surface layer by moving the nutrients down through the soil profile.

The second experiment was a study of horizontal distribution and stratification of soil nutrients, pH and organic matter over a range of soil textural groups. Nine sites were chosen for the study in fields which had been fertilized using a band application method and managed under a NT cropping system. Three sites were selected within each textural group: sand, clay and loam. As in the first experiment, a questionnaire was given to each farm cooperator requesting management history of the field.

At each location, a trench was dug along a 100 cm transect positioned perpendicular to the crop rows. Sample points were located every 20 cm along the transect starting at 0 cm giving a total of six points. The first point along the transect (0 cm) was always located within a crop row. Soil samples were taken by hand trowel at each transect point at 2 cm increments to a depth of 20 cm. These samples were analyzed for soil nutrient content (P, K, Mg, Ca) and pH. Similar samples to a depth of 16 cm were analyzed for organic matter content.

To identify horizontal stratification of nutrients, the standard deviations of the nutrient concentrations at each depth across the transect were determined. An analysis of varianee was conducted on these results. A numerically high standard deviation was considered indicative of a relatively high degree of stratification or variance in concentrations across the transect.

The number of years that each field had been managed under a NT system was significantly related to the horizontal variation in nutrient concentrations; the severity of horizontal stratification of nutrients increased with the number of consecutive years

under NT. Soil texture was a significant factor affecting the severity of horizontal stratification of K, Mg and to lesser extent, P. Only P stratification was significantly affected by the soil sample depth; the horizontal variation in P concentrations was greatest at 6 cm.

The results of the two experiments show that the stratification of nutrients in soils does exist, primarily within the soil sampling zone, and that its severity is directly related to tillage practice.

1.0 INTRODUCTION

1.1 The TED Component of SWEEP

The Soil and Water Environmental Enhancement Program (SWEEP) is a $30 million Federal-Provincial agreement designed to improve soil and water quality in southwestern Ontario. The primary aims of the program are to reduce phosphorous loadings in the Lake Erie basin from cropland runoff and to improve the productivity of southwestern Ontario agriculture by reducing or arresting soil erosion.

To assist in achieving this goal, SWEEP has been subdivided into a number of sub-programs, one of which is the Technology Evaluation and Development (TED) sub-program.

The TED component is centred at the federal research station at Harrow and is directed at field level evaluation of existing technologies, particularly developing new conservation methods under commercial farm conditions.

The objectives of the TED sub-program include:

- the development, evaluation and testing of agricultural technologies which are applicable to commercial farm management systems,

- close cooperation and involvement with the farm community to ensure the relevance of research to enhance adoption of successful technologies, and,

- coordination of the TED efforts with other components of the SWEEP program to minimize duplication, collect and share relevant economic and social data and maximize program effectiveness by considering options for technology transfer to a wide range of farm operators.

1.2 Nutrient Distribution and Stratification Resulting from Conservation Tillage

Phosphorous (P) stratification in soils managed under conservation tillage systems is of increasing concern to the agricultural community. Under conservation tillage systems which use broadcast placement of phosphorus fertilizers, there is a tendency for phosphorous to remain at or near the surface of the soil, giving rise to vertical stratification. Compared with conventional tillage systems, there is more risk of P fertilizer loss in conservation tillage systems due to erosion of the stratified P. Band placement of P fertilizer under conservation tillage systems may also lead to stratification in a horizontal dimension.

The extent to which soil management practices influence the distribution or redistribution of nutrients, the effect of resulting nutrient distribution on crop productivity, and the resulting implications to P losses from fields due to soil erosion, are not well understood. This study, conducted under normal farming operations, was designed to identify the relationship between field management and the stratification of phosphorous and other nutrients in both horizontal and vertical dimensions within the plough layer. The implications of these findings to the objectives of SWEEP are discussed.

1.3 Objectives

1.3.1 General Objectives

1. To study the effect of field management (cropping, tillage and fertilizer application) on the distribution patterns of four soil nutrients [phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca)], pH level and organic matter content of the soils.

2. To investigate the effect of conservation farming practices on the vertical and horizontal stratification of P and other nutrients resulting from the application of fertilizers.

3. To evaluate the implications of study findings to the objectives of the SWEEP program.

1.3.2 Specific Objectives

1. To conduct a survey of the patterns of distribution of phosphorus and other nutrients (K, Mg, Ca) in a vertical and horizontal grid over a large number of field conditions and management histories.

2. To study the distribution of soil parameters such as pH and organic matter in relation to that of P and the other nutrients.

3. To study the relationship between farm management history and the distribution patterns of nutrients in the soil.

4. To investigate the effect of conservation tillage practices on the distribution patterns of P and other nutrients resulting from fertilizer placement in various soil types.

5. To make recommendations for further studies on the effect of conservation management practices on nutrient distribution and stratification in soils and their implication to SWEEP and TED objectives.

1.4 Hypotheses

For the investigations aimed at achieving the above objectives, the following hypotheses were formulated.

1. Nutrient stratification in field soils does not have any clear relationship with farm management history.

2. Soil properties, such as pH, organic matter content and texture, do not have any clear effect on nutrient distribution and stratification in soils.

2.0 LITERATURE REVIEW

The major cause of nutrient loss from agricultural watersheds is uncontrolled soil erosion from agricultural fields (Sharpley and Smith, 1983; Burwell et al, 1987; Pesant et al, 1987). According to the PLUARG report (1978), the major non-point source of P loading to the Canadian side of the Great Lakes is cropland erosion and sediment deposition associated with extensive row cropping in Southwestern Ontario. Johnson et al (1979) reported that Total P in sediments decreased under conservation tillage but Available P and Solution P increased with crop residue cover. Rouseau et al (1987) noted that winter residue cover was effective in reducing P loading to lakes and waters.

Tillage has an effect on the nitrogen (N) and P composition of surface runoff (Romkins et al, 1973). Pesant et al, (1987) reported that no till reduced nutrient losses by 63 percent in runoff and by 94 percent in sediments. Other research has indicated that conservation tillage with adequate residue cover reduced P and N losses from cropland in watersheds (Burwell et al, 1987; Langdale et al, 1985).

Stratification of nutrients, especially slow moving nutrients such as P, has been observed in soils which have been under conservation tillage (Lauer, 1988a; Lauer, 1988b; Hargrove, 1985). Lauer (1988b) reported that P accumulated near the surface under conventional tillage when crop residues were left on the surface or near the surface. Using ammonium polyphosphate, monoammonium phosphate and triple super phosphate as surface applied P, Lauer observed that the depth of vertical penetration of P was 6.1 cm, 5.4 cm and 5.5 cm, respectively. Hargrove (1985) also measured depth of penetration of surface applied P under no till by sampling at 1 cm intervals. He observed that P penetrated to 10.4 cm. Fink and Wesley (1974) also reported on the slow movement of P and K under no tillage but noted that K moved faster than P.

Lauer (1988b) working with a calcareous subsoil, observed restricted movement of P in calcareous soil horizons. He reported that for all forms of surface applied phosphate the depth of penetration was on the average 3.1 cm. From these observations he concluded that vertical distribution of surface applied P depended on the reactivity of P fertilizer materials with the soil. Maclean et al (1971) found that Total P peaks in three soil profiles from Ontario occurred in the A horizon where organic phosphorus formed 74 percent to 81 percent of the Total P. In each case a significant amount of the Total P above the Ck horizon was organic phosphorus. Solution P and Available P were also observed to increase with an increase in crop residue cover (Spooner and Hjelmfelt

1985; Johnson et al, 1979). These studies suggest that adsorption by organic matter results in a reduction in the movement of phosphorus in soils.

Management history, such as tillage and fallow system, also affects the distribution of surface applied nutrients (Follet and Peterson, 1988; Stecker et al, 1981).

Band placement of phosphorus fertilizers in soils under conservation tillage and residue cover management has resulted in horizontal stratification of P between rows of crops (Hargrove, 1985; Sanders and Eghball, 1988; Bullen et al, 1983).

Since phosphorus moves slowly in soil, placement of P fertilizer is important in determining P availability to crops (Bullen et al, 1983; Sheard, 1980). Beauchamp et al (1976) showed that Extractable P did not affect the availability of P in subsoil layers but did so in surface layers. Banding of P fertilizers increased seed growth as much as five-fold as compared with broadcast placement while ammonium in the band increased the concentration of P in the band (Sheard, 1980). Compared with other methods of band placement including side-dressing, band placement at 2.5 cm directly below the seed was found to be most effective in increasing dry matter yield of soybean, Total P uptake and fertilizer P utilization (Bullen et al, 1983). Bullen et al (1983) noted that broadcasting the P fertilizer was not as effective in increasing grain yield as band placement. Hargrove (1985) studied the influence of tillage on nutrient uptake and noted that under notill, nutrients were more concentrated at the soil surface when compared with conventional tillage while, at the same time, nutrient status of plants under notill was higher than those under conventional tillage where the P fertilizer was mixed with the soil up to the depth of the plough layer.

Phosphorus content of soils is related to soil particle size distribution. Dong et al (1983) noted that P levels were higher in clay size fractions than in coarser fractions. Miller (1977) stated that the ratio of P concentration in a given soil fraction to that of total soil (P enrichment ratio) is related to the maximum particle size included in the fraction and that P enrichment in runoff sediment is related to its enrichment in clay and organic matter. Soil texture and organic matter content are, therefore, important parameters to be considered in the study of distribution and stratification of P in soils.

3.0 EXPERIMENT I

3.1 Objectives

To study the effect of the tillage system and field management history on the vertical distribution and stratification of soil nutrients, pH and organic matter.

3.2 Materials and Methods

3.2.1 Site Selection

The vertical stratification of nutrients was studied through sampling fields which had been fertilized using a broadcast method of application. This standardized the placement of the fertilizer at the soil surface and facilitated a comparison of the vertical nutrient movement through the soil profile.

We originally proposed to use sites operated by conservation farmers in the SWEEP pilot watershed project or by other conservation farmers with whom we had worked in the past. Most of these farmers have adequate historical field management records. However, these yielded only about one third of the sets of site conditions needed for the study. Consequently, to obtain enough suitable sites we contacted soil conservation advisors in the regions where site locations were preferred. A list of farmers known to be practising conservation farming was compiled through these contacts. Each was screened through a telephone interview to determine their willingness to cooperate and site suitability for the study.

Suitability for participation in the study was assessed on the grounds of

a) study design requirements (soil type, tillage practice),
b) adequate record keeping,
c) willingness to cooperate, and
d) consistency of management practices.

3.2.2 Field Management History

A questionnaire was designed to collect data on the management history of each of the fields sampled. A copy of the questionnaire is provided in Appendix I.

The questionnaire requested information regarding the following:

a) Tillage history;
b) Crop rotation - crop sequences, cover crops;
c) Management of surface residues;
d) Crop yields (as reported by the farmer);
e) Fertilizer application - type, method, time and rate of application;
f) Manure application, type and rate of application;
g) Liming history, if any; and
h) Pesticide use.

3.2.3 Experimental Design

In studying vertical nutrient stratification and distribution the effects of conservation tillage were compared to conventional tillage over a range of soil textural groups. For the purposes of this study, conventional tillage (CT) has been defined as the use of an unmodified mouldboard plough. Conservation tillage has been defined as either reduced tillage or notill. Reduced tillage (RT) is defined as the use of a chisel plough, and notill (NT) as the use of no tillage beyond that which occurs during the act of planting.

These tillage types were compared under three primary soil textural groups which included clayey, loamy and sandy soils.

Four locations were selected for each soil type within each tillage type giving a total of 36 sites. At each of the sites, data were collected from six sample points within the same soil textural area to characterize the soils with respect to relevant soil physical and chemical properties.

3.2.4 Soil Characterization

3.2.4.1 Organic Matter

At each of the six sample points within a site, a hole was dug with a shovel to a depth of 45 cm. Using a hand trowel, soil samples were taken from the side of the hole at 2 cm increments to a depth of 16 cm. Like samples from the six points were pooled together yielding one representative sample from each depth stage for analysis. The soil organic matter content was determined by the chromic acid digestion of Walkley and Black (1934) as modified in the Manual of Soil Sampling and the Methods of Analysis (MacKeague, 1981, Editor).

3.2.4.2 Particle Size Analysis

A bulk sample representing the 0-15 cm soil depth range was taken at each of six sampling points within a site and pooled together to yield one representative sample from each site. Soil particle size analysis was performed on the fine earth fraction (<2 mm) using the method outlined in the Canadian Soil Science Society's Manual of Soil Sampling and Methods of Analysis (MacKeague, 1981, Editor).

Soil textures were estimated in the field by hand texturing the soil.

3.2.4.3 Total Phosphorus (P)

A bulk sample representing the 0-15 cm soil depth range was taken at each of six sampling points within a site and pooled together to yield one representative sample from each site. Total phosphorus was determined using the method of Alsen and Dean (1965).

3.2.4.4 Soil Reaction pH

Soil samples were collected as for organic matter yielding samples at 2 cm increments to a depth of 20 cm, and below that at 5 cm increments to a depth of 45 cm. Soil pH was determined by the glass-electrode method on 1:1 soil - water paste (MacKeague, 1981, Editor).

3.2.4.5 Cone Penetrometer Resistance (CPR)

Cone penetrometer resistance measurements were made using a Rimik Cone Penetrometer. As an electronic recording penetrometer, the Rimik provides a continuous record of cone resistance through the soil profile to a depth of 45 cm in 1.5 cm increments. Measurements were taken at three points at each site in the vicinity of the soil sampling locations. Averages were calculated over three soil depth ranges (0-10 cm, 10-20 cm, and 20-45 cm) for use in characterizing the nutrient concentration changes (stratification).

3.2.4.6 Soil Bulk Density

Soil bulk density measurements were made using a Campbell-Pacific Nuclear (CPN) Portaprobe. Soil density is measured by inserting the gamma source, housed in a tube, beneath the soil surface through a punched access hole. Radiation is transmitted from the source to a detector in the base of the gauge. The density of the soil is determined by the radiation level at the detector.

Density readings were taken at 5 cm increments to a depth of 30 cm. Since these density readings were derived from the radiation emitted from the source (ie. 30 cm deep, 25 cm deep, etc.) to the detector at the soil surface, it was not possible to obtain a measurement of density at a specific depth. Instead, average densities over the entire depth were calculated. Measurements were averaged over the 30 cm depth and the mean density value used for statistical purposes.

3.2.4.7 Surface Water Infiltration

The rate at which water infiltrates across the soil atmosphere interface was measured using a Guelph Pressure Infiltrometer (GPI). One measurement was taken in the vicinity of the soil sampling locations.

3.2.5 Soil Nutrient Content

Soil samples were collected as described above for organic matter. Samples were taken at 2 cm increments to a depth of 20 cm, and below that at 5 cm increments to a depth of 45 cm. These soil samples were analyzed for plant-available phosphorus (P), potassium (K), magnesium (Mg), and calcium (Ca). The methods used were those recommended by the Ontario Soil Management Committee (1989).

3.2.6 Statistical Analysis

Soil nutrient concentration data (P, K, Mg, Ca and Organic Matter) were grouped into three strata: 0-10 cm, 10-20 cm, and 20-45 cm. These strata were objectively chosen to correspond to expected average depths of secondary and primary tillage. This grouping simplified the data set so that the results could be discussed in agronomically meaningful terms.

The data within these strata were statistically summarized to determine means and then regressed to calculate the slope over depth. The slope provided a relative gradient of nutrient concentration change with depth and thereby an indication of stratification which could be used for comparison. Use of the actual nutrient concentrations in the analysis was avoided since measurements of the cooperators fertilizer application rates were not within the scope of this project. Therefore, it was not possible to compensate for variations in fertilizer application rates between sites.

Because concentrations of applied nutrients generally tend to decline with soil depth, the slopes of the gradients were usually negative values; the more negative the value, the more severe the stratification. Stratification occurred in all soils under all tillage practices to some extent.

Within each stratum, an ANOVA was conducted using the slopes and the means in the following format.

Source	Degrees of Freedom
Tillage	2
Soil type	2
Tillage x Soil Type	4
Error	27
TOTAL	35

An ANOVA was also conducted using the stratum means of the measured physical soil properties (density, cone penetrometer resistance, infiltration and pH) and the gradient slope of organic matter as covariates. The ANOVA table was as follows.

Source	Degrees of Freedom
Tillage	2
Soil type	2
Tillage x Soil Type	4
Physical Property	1
Error	18
TOTAL	27

It should be noted that there were eight missing data points for the physical soil properties. Some of the questionnaire responses were also included as covariates in the above ANOVA.

The analysis outlined above was performed using Statgraphics (a statistical analysis computer program). The ANOVA tables have been included in Appendix II of this report.

3.3 Results and Discussions

3.3.1 Site Selection

A total of 36 sites was chosen for Experiment I. The geographic locations of the sample sites for Experiment I are shown in Figure 1.0.

Because of the difficulty experienced in finding sites which met the requirements of the study, it was not possible to keep the sample locations in close proximity to one another. Consequently, the results of the analysis were further complicated by climatic differences that could not be accounted for (ie. rainfall, heat units). Crop yield data were therefore not compared. Further variation to the treatments was introduced by minor variations in the management practices of each farmer and the equipment used. The tillage categories were also broadened in order to find the necessary number of sites and were generally based on primary tillage methods.

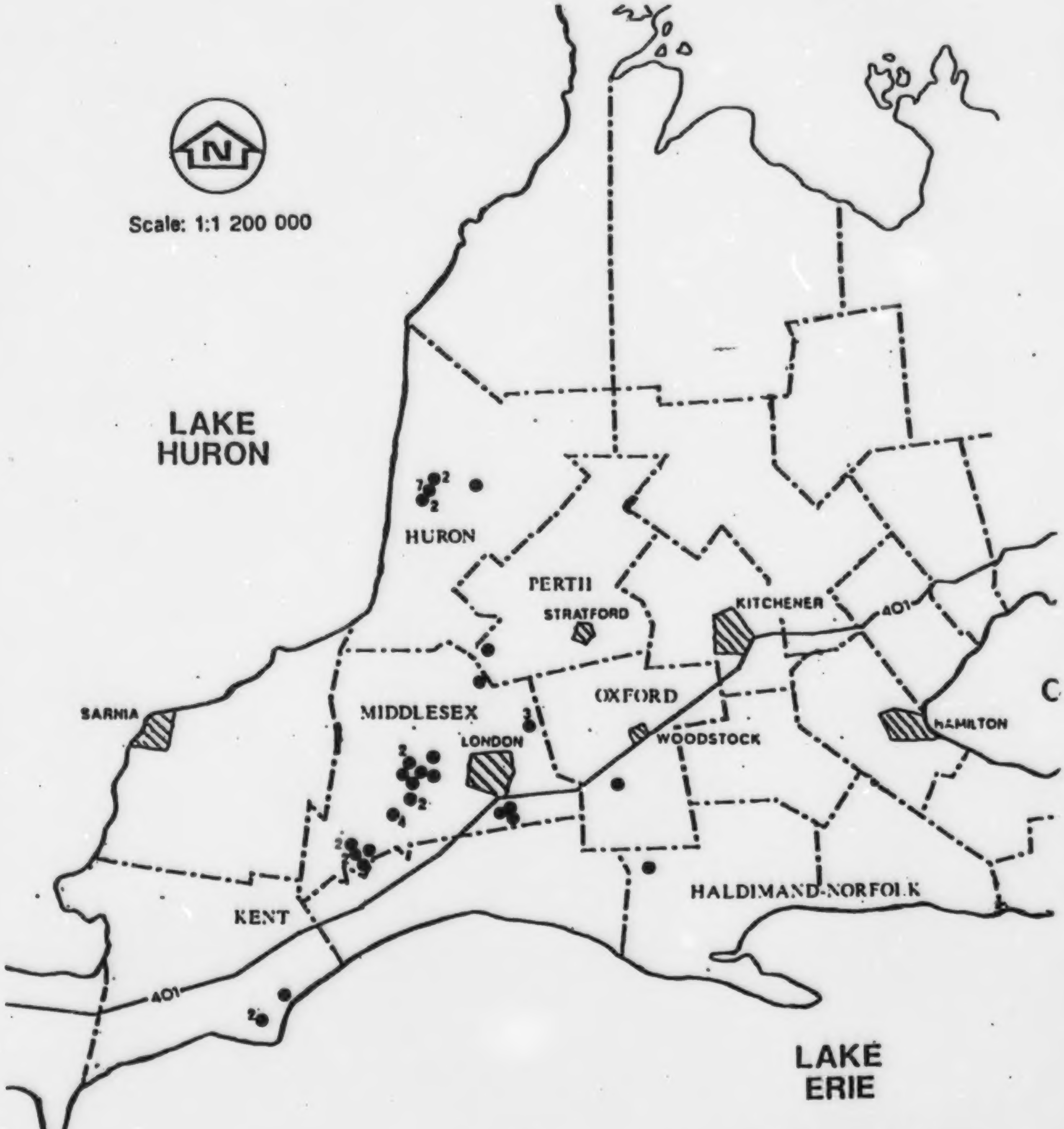
3.3.2 Field Management History

While this study was originally intended to focus on the effects of field management history on nutrient distribution and stratification, significant difficulties in obtaining adequate and consistent information from the cooperators constrained this analysis.

At the time of site selection and sampling, cooperators were generally not willing to take time to fill out the questionnaire (Appendix I). To accommodate their schedules, we left a copy of the questionnaire to be filled in at their convenience. Of the 36 sites sampled, questionnaires were secured for 28 sites. Of these, many of the responses were either incomplete or inconsistently answered.

In light of this data limitation, questionnaire responses were summarized and interpreted so that at least a limited evaluation of the effects of field management history on nutrient distribution and stratification could be carried out. These data were included wherever possible in the analysis as either covariates or main effects.

Figure 1.0: Location of Sample Sites



3.3.3 Soil Characterization

Table 1.0 summarizes the laboratory results of the bulk soil samples with respect to particle size distribution (PSD), pH, and Total P at the sites selected for Experiment I. Table 1.0 also includes the soil series of the sites as correlated with the characteristics of the relevant series described in the appropriate county soil report.

For the 36 sites sampled for Experiment I, data pertaining to the physical properties of the soil, including cone penetrometer resistance (CPR), dry bulk density and water infiltration rates at the soil surface were collected at all but eight sites. These latter sites were tilled by the cooperating farmers before it was possible to collect any of the soil physical property data.

3.3.3.1 Particle Size Analysis

Hand texturing of soils in the field was preformed at the time of site selection. Subsequently, PSD was determined in the laboratory. The results were used to confirm the soil textural classes for each site. The clay contents (the soil particles most reactive with available nutrient ions) varied significantly ($p < 0.01$) among the textural groupings that were established for this study.

3.3.3.2 Cone Penetrometer Resistance (CPR)

The CPR averages were significantly ($p < 0.01$) affected by both tillage and texture in the 0 to 10 cm and 10 to 20 cm layers. In the soil below the plough layer (20-45 cm) only soil texture continued to have a significant ($p < 0.01$) effect on resistance averages. The effects of tillage within the plough layer did, however, change slightly from the 0 to 10 cm layer to the 10 to 20 cm layer. While NT was more resistant to cone penetration than CT in both layers, RT appeared to increase the resistance to penetration for all soils in the 10 to 20 cm layer to levels in excess of those for the NT sites (Table 2.0). The reasons behind this pattern were not clear from the information gathered in this study.

Table 1:0: Particle size distribution, pH and total phosphorus of bulk soil samples taken from sites for Experiment I.

FIELD CODE	SOIL TYPE		TILLAGE*	PARTICLE SIZE DISTRIBUTION SAND (%)	SILT (%)	CLAY (%)	pH	TOTAL PHOSPHORUS (mg/kg)
CTC1	MURIEL	SILTY CLAY LOAM	CT	15.5	55.4	29.2	7.5	760
CTC2	MURIEL	CLAY LOAM	CT	25.6	35.3	39.1	7.4	1200
CTC3	MURIEL	CLAY LOAM	CT	35.6	29.9	34.5	7.0	880
CTC4	HURON	CLAY LOAM	CT	26.8	43.5	29.7	6.5	940
CTL1	BOOKTON	SANDY LOAM	CT	60.7	23.5	15.8	6.7	840
CTL2	HONEYWOOD	LOAM	CT	25.1	55.8	19.2	7.5	935
CTL3	MURIEL	SILT LOAM	CT	24.4	57.1	18.5	6.9	895
CTL4	BENNINGTON	LOAM	CT	27.4	55.5	17.0	6.8	915
CTS1	PLAINFIELD	SANDY LOAM	CT	74.8	17.1	8.7	7.1	820
CTS2	PLAINFIELD	LOAMY FINE SAN	CT	83.5	11.6	5.0	5.8	340
CTS3	PLAINFIELD	LOAMY FINE SAN	CT	83.4	8.9	7.7	7.5	630
CTS4	PLAINFIELD	SANDY LOAM	CT	74.9	20.2	4.9	5.2	925
NTC1	HARRISTON	SILTY CLAY LOAM	NT	18.6	51.7	29.7	7.0	870
NTC2	BROOKSTON	CLAY LOAM	NT	25.6	35.7	38.7	5.8	915
NTC3	HURON	LOAM	NT	31.8	47.7	20.5	7.2	770
NTC4	HARRISTON	SILTY CLAY LOAM	NT	22.8	48.5	29.2	7.4	780
NTL1	BURFORD	LOAM	NT	34.4	46.2	19.3	7.2	700
NTL2	HALDIMAND	LOAM	NT	16.9	67.7	15.5	7.2	920
NTL3	LISTOWEL	SILT LOAM	NT	9.9	68.8	21.3	7.5	960
NTL4	BRANT	SILT LOAM	NT	35.4	49.6	15.0	6.1	875
NTS1	BURFORD	LOAM	NT	44.2	44.1	11.8	7.2	825
NTS2	HALDIMAND	LOAM	NT	49.7	38.8	11.4	7.3	520
NTS3	PLAINFIELD	LOAMY SAND	NT	82.7	12.6	4.6	6.2	835
NTS4	FOX	LOAMY SAND	NT	82.0	11.5	6.5	7.5	835
RTC1	LISTOWEL	SILT LOAM	RT	23.2	52.3	24.5	7.3	710
RTC2	BRANTFORD	CLAY LOAM	RT	38.0	28.7	33.2	6.3	890
RTC3	BRANTFORD	CLAY LOAM	RT	36.9	26.5	36.7	7.5	875
RTC4	MURIEL	SILT LOAM	RT	17.4	58.2	24.4	7.5	915
RTL1	HONEYWOOD	SILT LOAM	RT	15.7	63.1	21.2	7.5	790
RTL2	BRANT	LOAM	RT	41.7	47.1	11.2	7.0	840
RTL3	BENNINGTON	LOAM	RT	24.4	61.3	14.3	7.0	945
RTL4	BENNINGTON	LOAM	RT	41.3	39.8	18.9	7.3	745
RTS1	FOX	LOAMY SAND	RT	81.7	13.3	5.0	7.2	740
RTS2	PLAINFIELD	LOAMY SAND	RT	83.6	12.6	3.8	6.1	860
RTS3	FOX	FINE SAND	RT	87.2	9.9	2.9	4.9	870
RTS4	BENNINGTON	SANDY LOAM	RT	63.5	29.5	7.1	7.5	745

* CT = Conventional Tillage
NT = No Tillage
RT = Reduced Tillage

Table 2.0 **Average cone penetrometer resistance values at different soil depth ranges and under different tillage systems.**

SOIL DEPTH RANGE	CONE PENETROMETER RESISTANCE (KPa)		
(cm)	NT	RT	CT
0-10	4118.3	3869.7	3570.2
10-20	4942.2	4995.4	4249.7
20-45	5237.6	5531.0	5038.4

It should be noted that cone penetrometer resistance values are affected by several soil characteristics including bulk density, soil moisture content, organic matter content, clay content and soil structure. Consequently, care must be taken when including the data as a covariate in the analysis of variance (ANOVA) for nutrient stratification. The effect of including these data in the analysis should aid in focusing on the exact causes of nutrient stratification by eliminating the effects that the above mentioned soil properties would contribute to the results. Because the resistance data are influenced by the main effects for which we are testing, the effects are further confounded.

3.3.3.3 Bulk Density

Tillage had a significant effect on bulk density ($p < 0.10$); however, the interaction between tillage and soil texture was also significant ($p < 0.05$). It is noteworthy that in the clayey and sandy soils, the average bulk density was greatest under RT (Table 3.0). This may be due to poor performance of RT (chisel ploughs) in shattering soil clods when moisture contents are too high. However, insufficient information was available on the soil condition at the time of tillage to be certain of the cause(s).

Table 3.0: Average bulk density of soils of different textures under different tillage systems.

SOIL TEXTURE	BULK DENSITY ($g\ cm^{-3}$)		
	NT	RT	CT
Clay	1.37	1.40	1.23
Loam	1.51	1.15	1.32
Sand	1.37	1.40	1.36

3.3.3.4 Surface Water Infiltration

Water infiltration rates (Kfs) as measured by the Guelph Pressure Infiltrometer (GPI) were significantly affected by both tillage and texture ($p < 0.10$ and $p < 0.05$, respectively). NT soils had significantly slower rates of water infiltration than soils under RT or CT. Soil density was significantly related to infiltration rates when included in the analysis as a covariate and resulted in tillage no longer being a significant factor. Therefore, it may be concluded that the effects of tillage on infiltration rates were in part due to the effects of tillage on soil bulk density.

Loam soils had the highest infiltration rates, significantly greater than those in clay soils, but not significantly different from sandy soils. Clay soils were the least permeable to water at the soil surface and were also not significantly different from sandy soils.

The effects of soil texture on infiltration rates as noted are atypical relative to current knowledge thus leaving some doubt as to the integrity of this specific data base.

Table 4.0: Average water infiltration rates of soils of different textures under different tillage systems.

SOIL TEXTURE	WATER INFILTRATION RATE ($cm\ min^{-1}$)		
	NT	RT	CT
Clay	0.0234	0.4211	0.0078
Loam	0.1328	1.5580	1.5610
Sand	0.1623	0.4779	0.7718

3.3.3.5 Organic Matter Content and pH

Tillage had a significant effect on the slope of the change in organic matter content in the 0 to 10 cm layer ($p < 0.01$). The stratification of organic matter was significantly more severe under NT than RT or CT. While RT also exhibited a slight decrease in organic matter content with depth, CT sites showed a slight increase with depth (Figure 2.0). These trends were most likely a function of the different degrees of soil mixing associated with the three tillage types.

The mean soil pH of each layer was not significantly affected by either tillage or texture.

3.3.4 Soil Nutrient Stratification

In the context of this report, stratification of nutrients refers to the change in the concentration of nutrients with depth.

3.3.4.1 Phosphorus (P)

There were no significant differences in the slope of the change in P concentration with depth between soil depth ranges, tillage practices, or soil textures. However, the interaction of tillage with depth was significantly related to P stratification ($p < 0.05$).

When comparing P stratification under the two extremes of tillage intensities, opposite trends were observed. Under NT, P stratification was most severe in the 0 to 10 cm soil depth range and least severe in the 20 to 45 cm soil depth range. Under CT, this trend was reversed. Diagrammatically, these trends translated into the generalized P gradients shown in Figure 3.0. There we observe that over the plough layer (0-20 cm) there was very little stratification under CT in contrast to NT, where the most severe stratification was observed at the soil surface.

P stratification over the three soil depth ranges was less clear under RT. The P stratification in the 0 to 10 cm and 20 to 45 cm layers displayed a similar trend to that of NT, although less pronounced. However, the 10 to 20 cm layer, unlike in NT, exhibited the least severe stratification.

Figure 2.0: Effect of tillage system on the distribution of organic matter in soil.

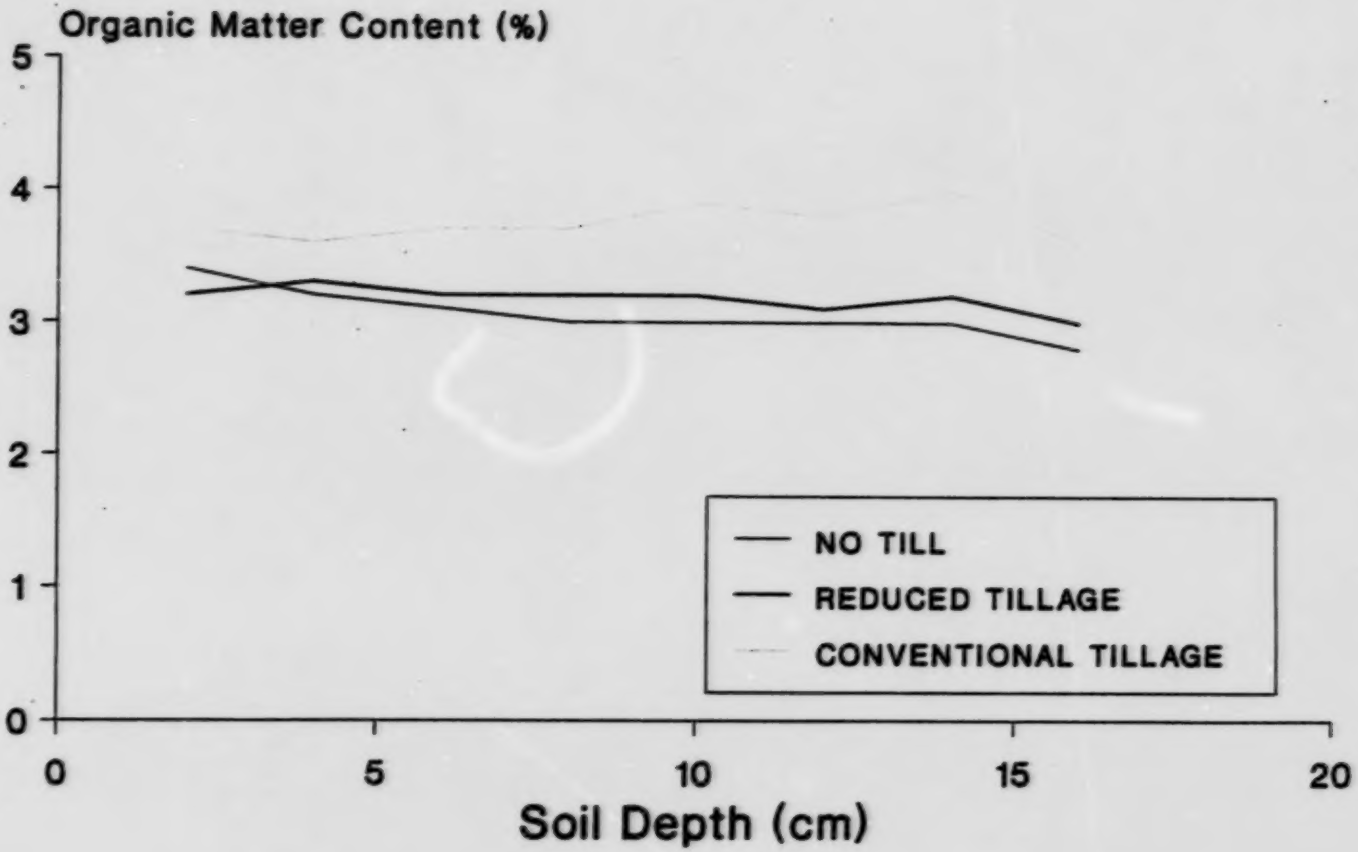
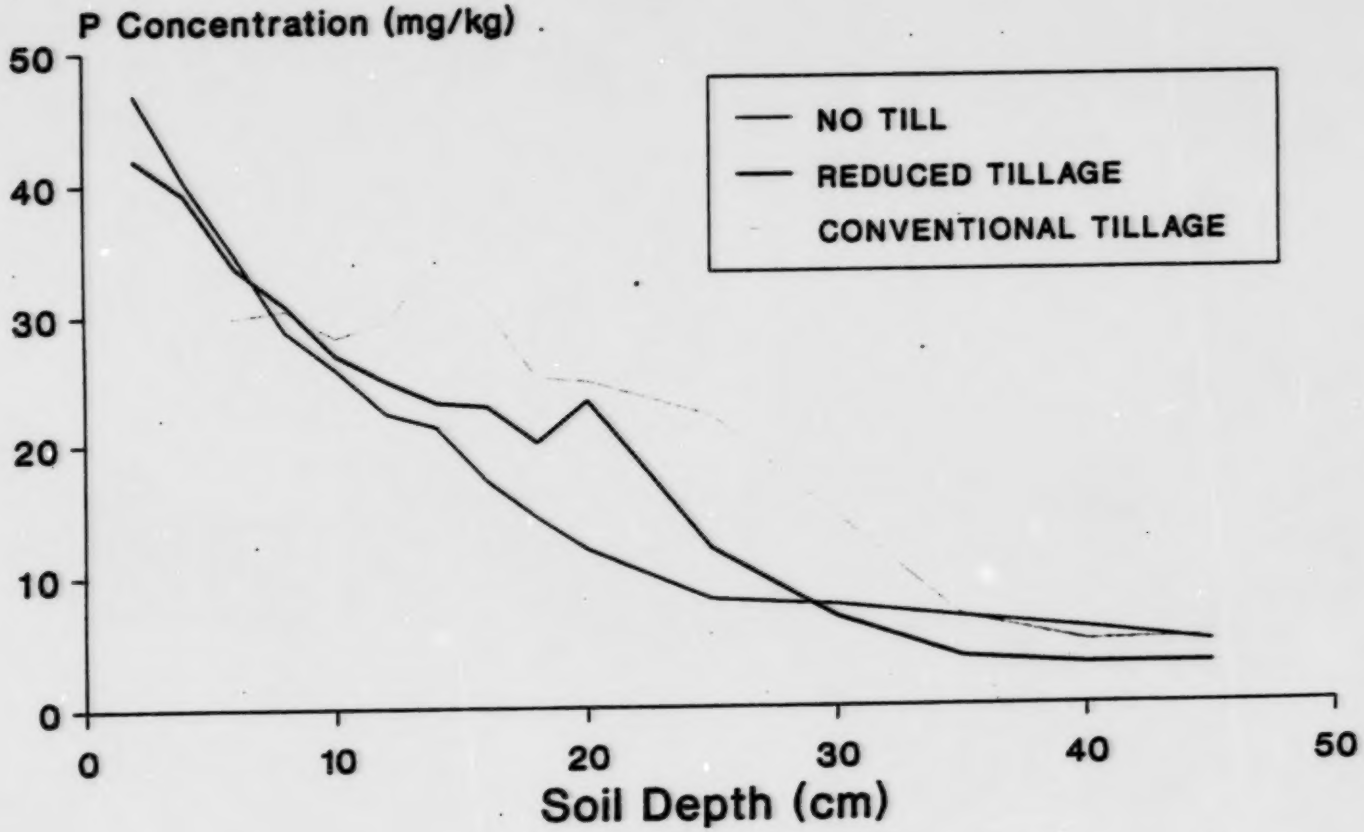


Figure 3.0: Effect of tillage system on the distribution of phosphorus (P) in soil.



3.3.4.1.1 0 to 10 cm Soil Depth Range

The type of tillage system used had a significant effect ($p < 0.05$) on the stratification of P in the 0 to 10 cm soil depth range.

The most severe stratification was observed in NT sites followed by RT and finally CT. Cone penetrometer resistance (CPR) and bulk density data were significantly related to P stratification ($p < 0.10$) and when included in the analysis as a covariate, resulted in soil texture becoming significant ($p < 0.10$ and $p < 0.05$, respectively). Although infiltration data were not significantly related to P stratification, it too had a similar effect on the significance of tillage and texture.

The reason for the increased significance of texture by the inclusion of these covariates in the analysis was not clear. However, these results were not surprising considering the tendency of P to be adsorbed by the colloidal surfaces of heavier textured soils (Oloya and Logan, 1980). Stratification in sandier soils has been observed to be less significant (Karlan et al. 1984) and was attributed to the lack of colloidal surfaces.

The mean Ca concentration was significantly related ($p < 0.01$) to P stratification, and its inclusion as a covariate in the analysis resulted in the effects of texture becoming very insignificant ($p = 0.95$). This would suggest that the effects of texture were in part due to the concentrations of Ca. Where soil pH is above 7.0 the presence of Ca ions can cause the precipitation of added P; however, soil pH did not prove to be significantly related to P stratification in this study. The Ca mean concentrations were significantly related to texture ($p < 0.01$) with the highest concentrations being observed in the clay soil. Consequently, it was not possible to assess whether the presence of colloidal surfaces or Ca ion concentrations had the most significant effect on the results of this study.

The gradient for organic matter content with depth was significantly related ($p < 0.10$) to P stratification, and its inclusion as a covariate in the analysis resulted in the effects of tillage and texture becoming insignificant. Also, tillage was a significant factor affecting organic matter stratification ($p < 0.01$), thus indicating that the effects of tillage on organic matter stratification were in part responsible for the stratification of P.

None of the results of the questionnaire proved to be significant factors in the stratification of P.

3.3.4.1.2 10 to 20 cm Soil Depth Range

Neither tillage nor soil texture were significant factors affecting the gradient of P concentration in the 10 to 20 cm soil depth range. However, when the CPR data were included in the analysis, although not significantly related to P stratification, the significance of tillage ($p < 0.10$) improved.

The general lack of significance may be attributed to several possible influences.

1. Soils in RT and CT are highly disturbed by the tillage operation at that depth and therefore reduce any presence of stratification;

2. Soils in NT are too far below the surface to be significantly affected by applications of P at the surface and therefore stratification is minimal.

Bulk density and water infiltration rates were both significantly related to P stratification ($p < 0.05$); however, their inclusion in the analysis as covariates did not affect the significance of tillage or soil texture.

Phosphorus stratification in the 10 to 20 cm soil depth range was not significantly affected by any variable resulting from the questionnaires.

3.3.4.1.3 20 to 45 cm Soil Depth Range

Tillage practice and soil texture did not significantly affect the stratification of P in the 20 to 45 cm soil depth range. It was noted, however, that the effect of tillage on P stratification was greater in this depth range ($p = 0.14$) than in the 10 to 20 cm depth range ($p = 0.34$). Also of note was the fact that, in the 20 to 45 cm soil depth range, CT resulted in significantly greater stratification than NT, unlike the 0 to 10 cm depth range where NT resulted in the most severe stratification (Figure 2.0). This was attributed to the movement of P to the bottom of the plough layer by CT. The elevated levels at this point caused stratification in the 20 to 45 cm range to be exaggerated. Nutrient levels under NT, however, were not impacted to any great degree by the surface applications of P and subsequently appeared to be the least stratified.

None of the covariates for soil physical properties proved to be significantly related to the P stratification when included in the analysis.

3.3.4.2 Potassium (K)

The gradient in K levels in the soil varied significantly among soil depth range ($p < 0.01$) and tillage practices ($p < 0.10$). As was observed earlier with P levels, K was most stratified in the 0 to 10 cm soil depth range when NT was practised, whereas in the 20 to 45 cm depth range, K stratification was most severe under CT (Figure 4.0).

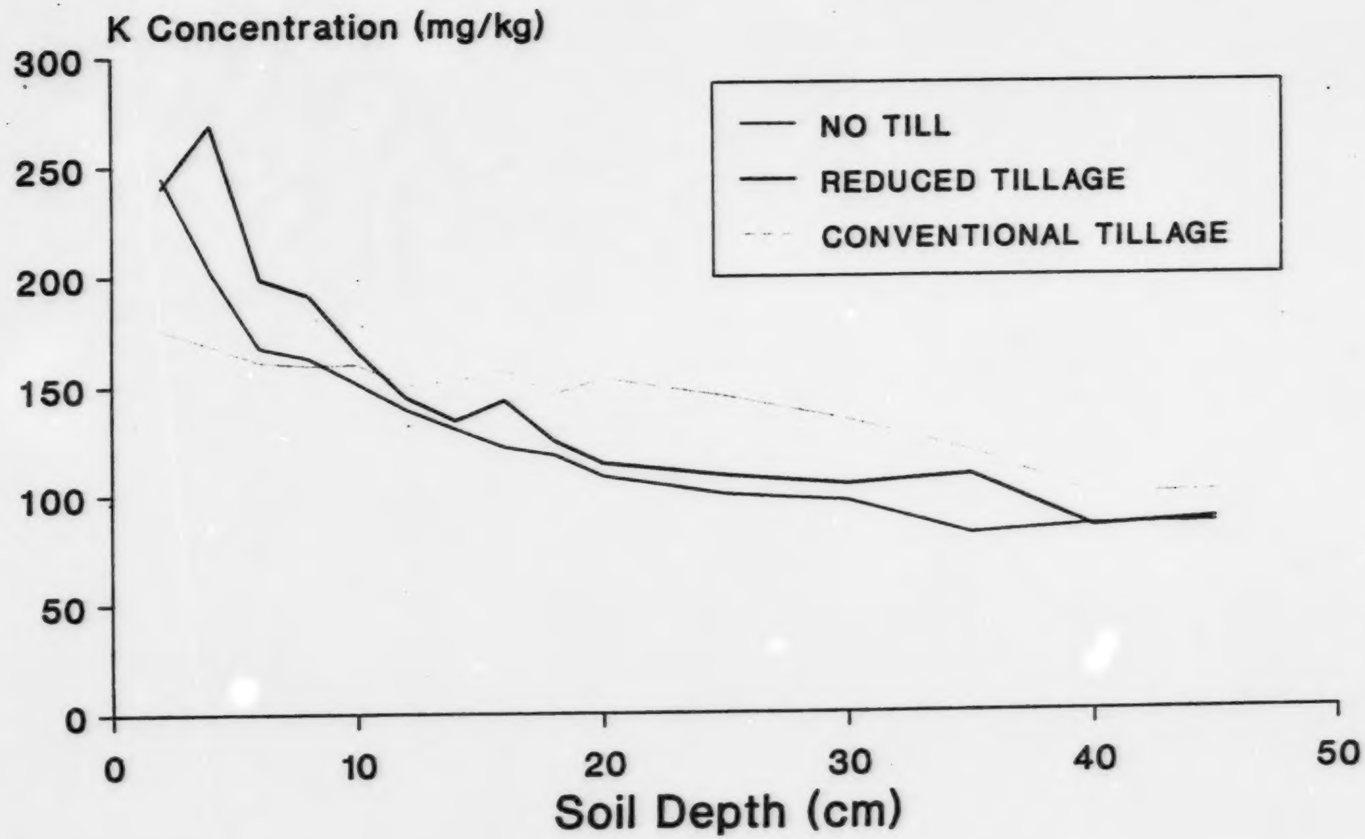
The reasons for these trends are the same as those given for P stratification. CT resulted in very little stratification in the plough layer due to soil mixing, and NT maintained the greatest concentrations of K at the soil surface and accumulated K with successive applications. The severe gradients found in the 20 to 45 cm layer under CT were caused by soil mixing which elevated the concentrations of K at the bottom of the plough layer to levels well in excess of those found in the unaffected soil below the plough layer.

3.3.4.2.1 0 to 10 cm Soil Depth Range

In the 0 to 10 cm layer tillage had a significant effect on K stratification ($p < 0.05$). Across all textural types, significantly less stratification of K was observed in soils under CT than under RT or NT. There was no significant difference between stratification under RT and NT.

Cone penetrometer resistance was significantly related to K stratification ($p < 0.05$) and its inclusion as a covariate in the analysis resulted in tillage no longer being a significant factor. The effects of tillage on CPR were therefore partly responsible for the stratification of K in the 0 to 10 cm layer.

Figure 4.0 : Effect of tillage system on the distribution of potassium (K) in soil.



3.3.4.2.2 10 to 20 cm Soil Depth Range

The only factor to significantly influence the stratification of K in the 10 to 20 cm layer was tillage ($P < 0.10$). As in the 0 to 10 cm layer, NT and RT resulted in significantly greater stratification than CT.

Of the questionnaire data, the inclusion of the response to the question of whether cover crops were used (yes/no) proved to be a significant ($p < 0.01$) factor affecting the stratification of K. Stratification was less severe when cover crops were used than when they were not.

3.3.4.2.3 20 to 45 cm Soil Depth Range

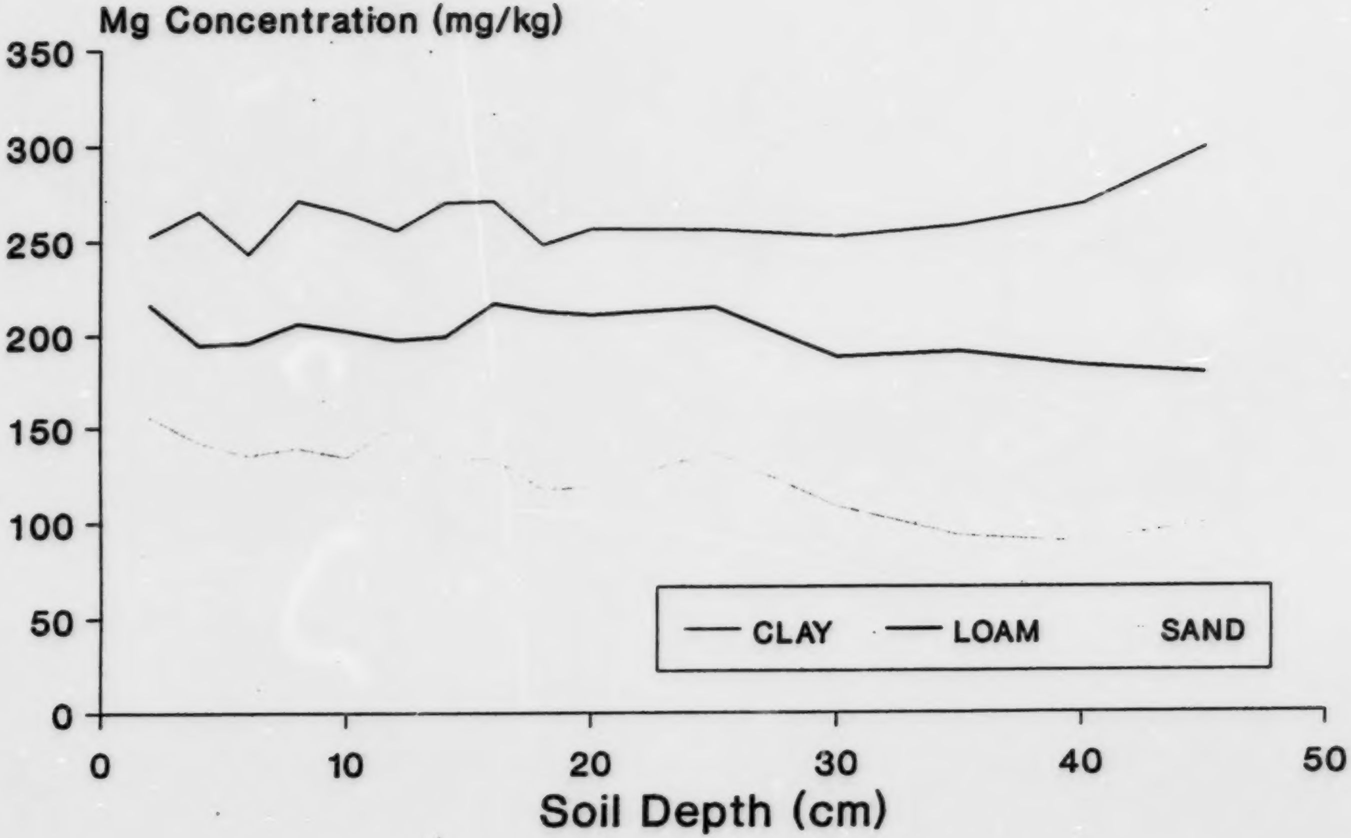
Tillage had a significant effect on the stratification of K in the 20 to 45 cm layer ($p < 0.10$). In contrast to the 0 to 10 cm layer, stratification was most severe in the soils under CT, and was significantly different from the soils under NT. Stratification in soils under RT was not significantly different from either NT or CT. This again supports the hypothesis that the elevated levels of nutrients brought to the bottom to the plough layer by soil mixing in CT resulted in the formation of a nutrient gradient (or stratification) below the plough layer.

Cone penetrometer resistance was significantly related to K stratification ($p < 0.05$) and its inclusion as a covariate in the analysis resulted in tillage no longer being a significant factor. However, both texture and the interaction between tillage and texture increased in significance ($P > 0.10$).

3.3.4.3 Magnesium (Mg)

Tillage and texture both significantly affected ($p < 0.05$) the Mg concentration gradients. The effects of soil texture have been summarized in Figure 5.0. The stratification of Mg in clay soils was statistically similar to that in loamy soils, but different from sandy soils. Mg concentrations actually increased with depth in the clay soils presumably due to the inherently higher Mg concentrations found in these soils. The concentration of Mg in loamy and sandy soils both decreased with depth. This may have been a result of the

Figure 5.0 : Effect of soil texture on the distribution of magnesium (Mg) in soil.



inherently lower Mg concentration in these soils when compared to the concentration of Mg applied to the surface through fertilization.

The effects of tillage on the stratification of Mg have been summarized in Figure 6.0. The decline in Mg concentration with soil depth was significantly greater under NT than under RT or CT.

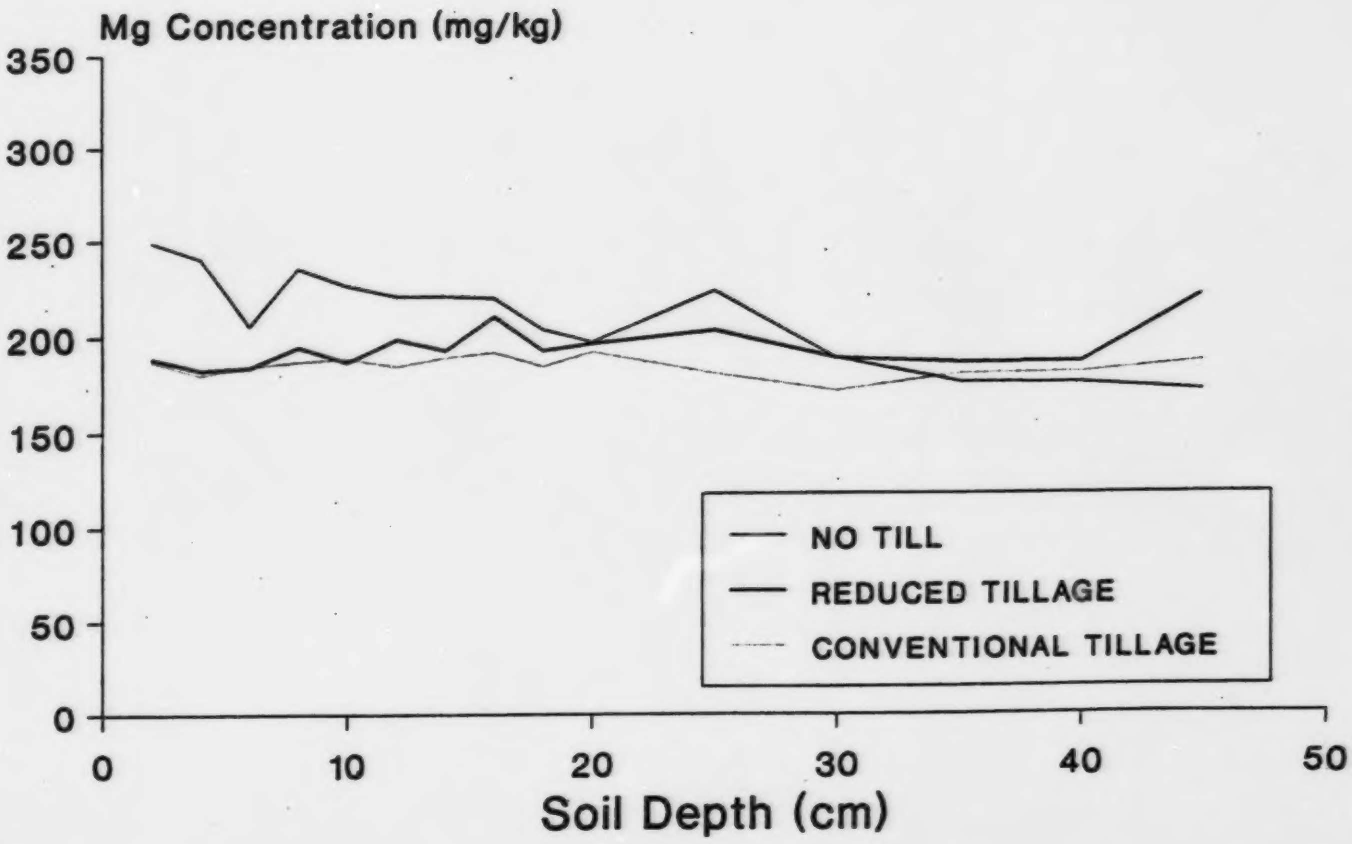
3.3.4.3.1 0 to 10 cm Soil Depth Layer

Neither tillage or soil texture had a significant effect on the stratification of Mg in the 0 to 10 cm soil depth range. While none of the soil physical property data (CPR, bulk density, water infiltration) were significantly related to the stratification of Mg when included as a covariate in the analysis; they each improved the significance of texture ($p < 0.10$). As such it may be assumed that part of the variance observed in the relationship of texture to Mg stratification was a function of the variance found in those soil properties.

The inclusion of the stratification values of organic matter content as a covariate ($p < 0.10$) improved the significance of texture ($p < 0.05$). Therefore, it may be concluded that part of the variance observed in the relationship of texture to Mg stratification was a result of changes in the gradient of organic matter content. The relationship of texture to Mg stratification revealed that clay soils were the least stratified and sandy soils the most. This may be a function of relatively higher natural concentrations of Mg in clay soil compared to coarser textured soils. This conclusion was substantiated by a statistical analysis of the mean Mg concentration which revealed it to be significantly ($p < 0.10$) higher in the heavier textured soils.

None of the questionnaire responses proved to be significantly related to Mg stratification when included as covariates in the analysis.

Figure 6.0 : Effect of tillage system on the distribution of magnesium (Mg) in soil.



3.3.4.3.2 10 to 20 cm Soil Depth Range

Soil texture had a significant effect on stratification of Mg ($p < 0.05$). While sandy and clayey soils both indicated a decrease in Mg concentration with depth, loamy soils exhibited a slight increase (Figure 4.0). The reasons for this trend were not clear.

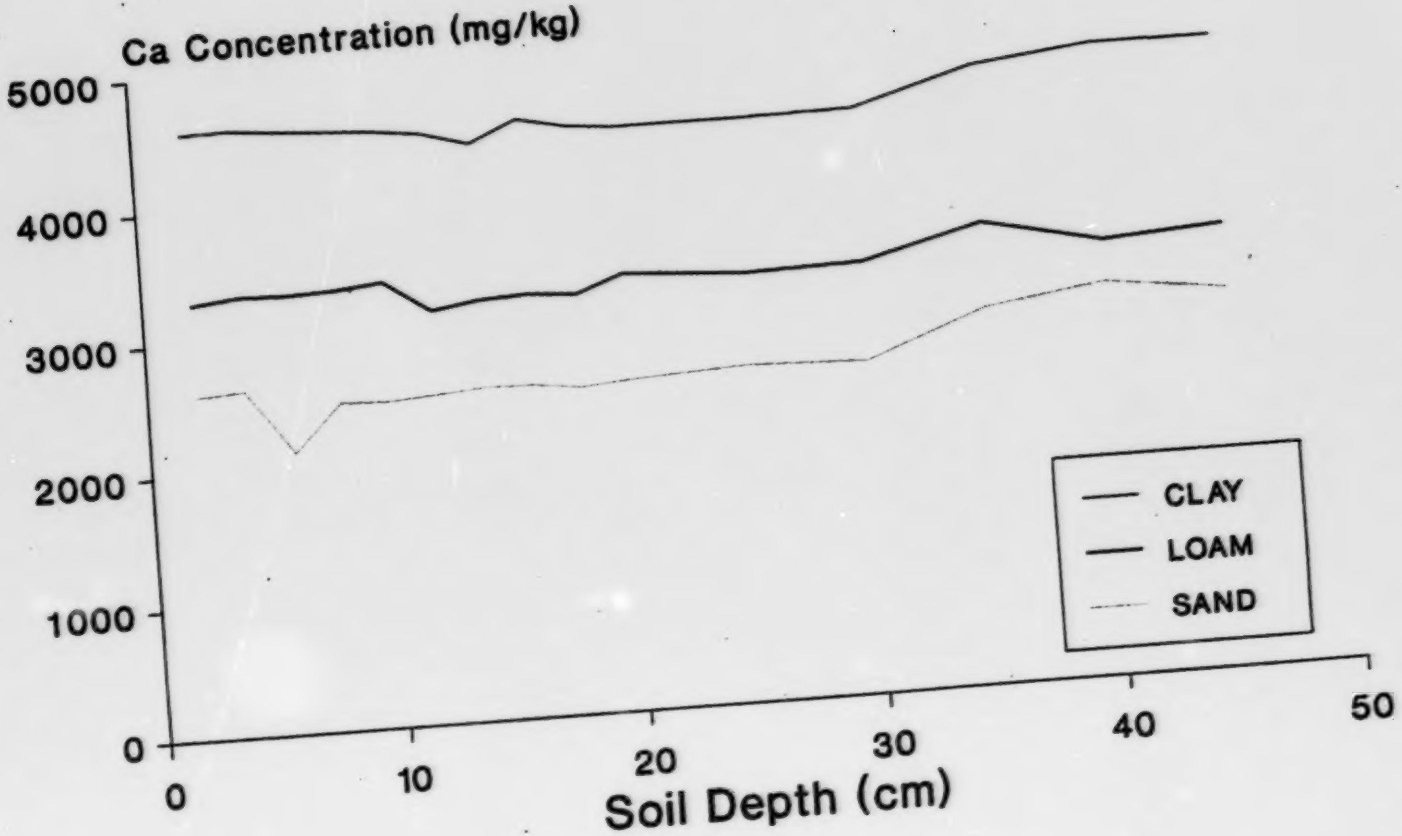
3.3.4.3.3 20 to 45 cm Soil Depth Range

The degree of stratification of Mg in the 20 to 45 cm layer was significantly ($p < 0.05$) related to soil texture when the CPR data were included in the analysis as a covariate. In clay soils, Mg concentrations increased with depth, unlike loamy and sandy soils which showed a decline in Mg concentrations with depth (Figure 4.0). The increase in the clay soils may be attributed to the higher Mg concentrations in the parent material. The decreases in Mg levels in the loamy and sandy soil would suggest that the inherent concentrations of Mg in the parent materials were relatively low compared to those that were applied at the surface. The effects of tillage redistributing nutrients to the bottom of the plough layer may have been responsible for the stratification observed below the plough layer as was observed in the P stratification.

3.3.4.4 Calcium (Ca)

There were no significant differences in the slope of the change in Ca concentration with depth between soil depth ranges, tillage practices, or soil textures. The mean Ca concentration within the layers was observed to be significantly ($p < 0.01$) related to the texture of the soil. The coarser textured sandy and loamy soils had a significantly lower mean Ca concentration than did the heavier textured clayey soils (Figure 7.0). This was most likely a function of the Ca content of the soil parent material.

Figure 7.0: Effect of soil texture on the distribution of calcium (Ca) in soil.



3.4 Summary

Several factors appeared to dominate in the development of vertically stratified layers of nutrients in the soil profile as a result of conservation tillage. Those factors were

1. soil mixing,
2. soil texture,
3. soil physical properties,
4. soil fertility prior to fertilizer application, and
5. soil organic matter content.

The tillage system used affected the vertical distribution of nutrients in the soil sampling layer. For example, the gradient of P decline in the 0 to 10 cm soil depth range was significantly greater under NT than CT, indicating that conservation tillage resulted in uneven vertical distribution of P in the soil. In both the 0 to 10 cm and 10 to 20 cm depth ranges, CT resulted in significantly less K stratification than RT or NT. In addition, although the gradient of Mg decline in the 0 to 10 cm depth range was not significantly affected by tillage, the actual concentration of Mg was significantly greater under NT.

Therefore, the mixing of soil which occurred under CT and to a lesser extent RT, reduced the nutrient stratification in the plough layer by mixing the applied fertilizer throughout. The absence of this mixing in NT promoted stratification by leaving applied nutrients of previous applications at the surface and resulted in a cumulative effect.

Soil texture may influence stratification in several ways. The colloidal surfaces of clay particles have the ability to fix or retain applied P and K. Soils containing larger fractions of clay particles will therefore have a greater ability to fix more P and K at the point at which they are applied (the soil surface) resulting in increased stratification. In addition, soil texture affects the rate of water infiltration through the soil.

Water infiltration rates, CPR and bulk density were significantly related to the degree to which nutrient stratification occurred. While each of these properties was affected by other soil physical characteristics, tillage practices also had a significant effect on their values. It was also evident that these properties may effect stratification irrespective of the impacts of tillage. Water infiltration was perhaps the most important of these properties with respect to its impact on the leaching of nutrients in solution through the

soil profile. The higher infiltration rates associated with sandy soils enhanced the leaching of nutrients from the soil surface and affected the potential development of a stratified surface layer by moving the nutrients down through the soil profile.

The organic matter content of soils was also affected by the soil mixing which occurred in CT and RT. Under NT conditions, soil organic matter content was stratified with depth just as the applied nutrients.

4.0 EXPERIMENT II

4.1 Objective

To study the effect of tillage system and field management history on the horizontal distribution and stratification of soil nutrients, pH and organic matter.

4.2 Materials and Methods

4.2.1 Site Selection

Sites were selected in fields which met three priority criteria including

i) a soil texture either a clay, loam or sandy category,
ii) fertilized using a band application method, and,
iii) managed under a NT cropping system.

It was anticipated that the placement of the fertilizer in a discrete and undisturbed location below the soil surface, as in NT, would make it possible to monitor the movement of nutrients horizontally within the soil profile. The restriction to NT systems was based on the assumption that CT and RT, through soil mixing, would obliterate any carryover effects in horizontal nutrient distribution from the band application of fertilizers in previous years. It should be noted that to meet the above criteria, it was not possible to find sites with identical crops and row widths. Since actual field conditions were required for this study, the location of fertilizer bands from previous years was not available.

It was originally assumed that many of the sites could be identified by making use of the information already available through the SWEEP sub-watershed project and conservation farmers with whom Ecologistics Limited has worked with in the past. However, these contacts only yielded approximately one third of the sites necessary to complete the study.

The limitations on finding suitable sites as discussed in section 3.2.1 for Experiment I, applied equally in this case as well.

4.2.2 Field Management History

The questionnaire as described in section 3.2.2 was also used for Experiment II.

4.2.3 Experimental Design

Three soil textural groups, clay, loam and sand, were sampled. Three sample locations were selected within each of the textural groups resulting in nine sample collection locations. At each location, a 100 cm transect was positioned perpendicular to the crop rows. Sample points were located every 20 cm along the transect starting at 0 cm giving a total of six points with the 0 cm point always located within a crop row. This sampling method ensured that a minimum of two rows would be crossed and the chance of picking up a band location would be high.

4.2.4 Soil Characterization

4.2.4.1 Organic Matter

At each of the nine sample locations, a trench was dug with a shovel to a depth of 20 cm. The trench was positioned along a 100 cm transect perpendicular to the crop rows. Using a hand trowel, soil samples were taken from the side of the trench at the six sample points along the horizontal transect. At each transect point, samples were taken along the vertical axis at 2 cm increments to a depth of 16 cm. The soil organic matter content was determined by the chromic acid digestion of Walkley and Black (1934) as modified in the Manual of Soil Sampling and the Methods of Analysis (MacKeague, 1981, Editor).

4.2.4.2 Particle Size Analysis

A bulk sample representing the vertical 0-15 cm soil depth range was taken at each of the six sampling points within a transect, and pooled together to yield one representative sample from each site. Soil particle size analysis was performed on the fine earth fraction (<2 mm) using the method outlined in the Canadian Soil Science Society's Manual of Soil Sampling and Methods of Analysis (MacKeague, 1981, Editor).

4.2.4.3 Total Phosphorus (P)

A bulk sample representing the vertical 0-15 cm soil depth range was taken at each of the six sampling points within a transect, and pooled together to yield one representative sample from each site. Total phosphorus was determined using the method of Alsen and Dean (1965).

4.2.4.4 Soil Reaction pH

A bulk sample representing the vertical 0-15 cm soil depth range was taken at each of six sampling points within a transect, and pooled together to yield one representative sample from each site. Using a hand trowel, separate samples were also taken along the vertical axis from each transect point at 2 cm increments to a depth of 20 cm.

4.2.4.5 Cone Penetrometer Resistance (CPR)

Cone penetrometer resistance measurements were made using a Rimik Cone Penetrometer. As an electronic recording penetrometer, the Rimik allows for the acquisition of a continuous record of cone resistance through the soil profile to a depth of 45 cm in 1.5 cm increments. One measurement was taken at each site.

4.2.4.6 Soil Bulk Density

Soil bulk density measurements were made using a Campbell-Pacific Nuclear (CPN) Portaprobe. The use of these portable gauges is widespread in the agriculture and construction industries. Densities are measured by inserting the gamma source, housed in a tube, beneath the soil surface through a punched access hole. Radiation is transmitted from the source to a detector in the base of the gauge. The density of the soil is determined by the radiation level at the detector. One measurement of bulk density was taken at each site.

4.2.4.7 Surface Water Infiltration

The rate at which water infiltrates through the soil from the soil surface was measured using a Guelph Pressure Infiltrometer (GPI). One measurement was taken using this instrument at each site.

4.2.5 Soil Nutrient Content

Soil samples were collected as described for organic matter, yielding samples along the vertical axis at 2 cm increments to a depth of 20 cm. These soil samples were analyzed for plant-available phosphorus (P), potassium (K), magnesium (Mg) and calcium (Ca). The methods used were those recommended by the Ontario Soil Management Committee (1989).

4.2.6 Statistical Analysis

To identify horizontal stratification of nutrients, the standard deviations of the nutrient concentrations at each depth across the transects were determined. An analysis of variance was conducted on these results with the understanding that a numerically high standard deviation would be indicative of a relatively high degree of stratification or variance in concentrations across the transect.

The ANOVA table was as follows

Source	Degrees of Freedom
Soil type	2
Depth	9
Depth x Soil Type	18
Error	60
TOTAL	89

The soil physical property data were included as covariates in the analysis. Aside from the number of years under notill, there was insufficient questionnaire data for it to be included in the analysis.

The analysis outlined above was performed using Statgraphics (a statistical analysis computer program). The ANOVA and mean separation results have been included in Appendix III of this report.

4.3 Results and Discussions

4.3.1 Site Selection

A total of nine sites were chosen for Experiment II. The geographic locations of the sample sites is shown in Figure 1.0. Fields were chosen that had been fertilized using a band application method and managed under NT. Two of the fields were planted to soybeans, the other seven to corn.

4.3.2 Field Management History

The discussion in section 3.3.2 related to information obtained from farm cooperators applies here as well.

4.3.3 Soil Characterization

Table 5.0 summarizes the laboratory results of the bulk soil samples with respect to PSD, pH, and Total P of the sites selected for Experiment II. In addition, Table 5.0 includes the soil series at each site.

Of the nine sites sampled for Experiment II, data pertaining to the physical properties of the soil, including cone penetrometer resistance (CPR), dry bulk density and water infiltration rates at the soil surface were collected at all but one site. This latter site was tilled by the co-operating farmer before it was possible to collect any of the soil physical property data. At each of the eight sites where physical property data were collected, one reading was taken for each property.

Table 5.0 Particle size distribution, pH and total phosphorus of bulk soil samples taken from sites for Experiment II.

FIELD CODE	SOIL TYPE		TILLAGE*	PARTICLE SIZE DISTRIBUTION SAND (%)	SILT (%)	CLAY (%)	pH	TOTAL PHOSPHORUS (mg/kg)
BANDC1	HARRISTON	CLAY LOAM	HNT	28.5	42.5	28.9	7.2	880
BANDC2	BRYANSTON	SILTY CLAY LOAM	HNT	13.7	54.4	31.8	7.6	910
BANDC3	BRANTFORD	SILTY CLAY LOAM	HNT	11.4	59.6	29.0	6.8	760
BANDL1	BURFORD	LOAM	HNT	45.8	33.8	20.6	7.1	820
BANDL2	LISTOWEL	LOAM	HNT	41.4	44.2	14.4	7.3	790
BANDL3	LISTOWEL	SILT LOAM	HNT	26.5	57.2	16.3	7.2	880
BANDS1	DONNYBROOK	LOAMY SAND	HNT	78.3	14.4	7.4	7.3	720
BANDS2	DONNYBROOK	LOAMY FINE SAN	HNT	78.1	16.1	5.8	7.3	750
BANDS3	VITTORIA	SAND	HNT	88.0	8.7	3.3	5.7	830

* HNT = No tillage (banded fertilizer application)

4.3.3.1 Particle Size Analysis

Soils were hand textured at the time of site selection. Subsequent particle size distribution results were used to identify soil textural classes. The clay contents (the soil particles most reactive with available nutrient ions) varied significantly ($p < 0.01$) among the textural classes, as established for this study.

4.3.3.2 Soil Reaction pH

The standard deviation of the soil pH among points across a horizontal transect was significantly affected by soil texture ($p < 0.01$), with sandy soil showing increased horizontal variation compared to clayey and loamy soil.

4.3.3.3 Organic Matter Content

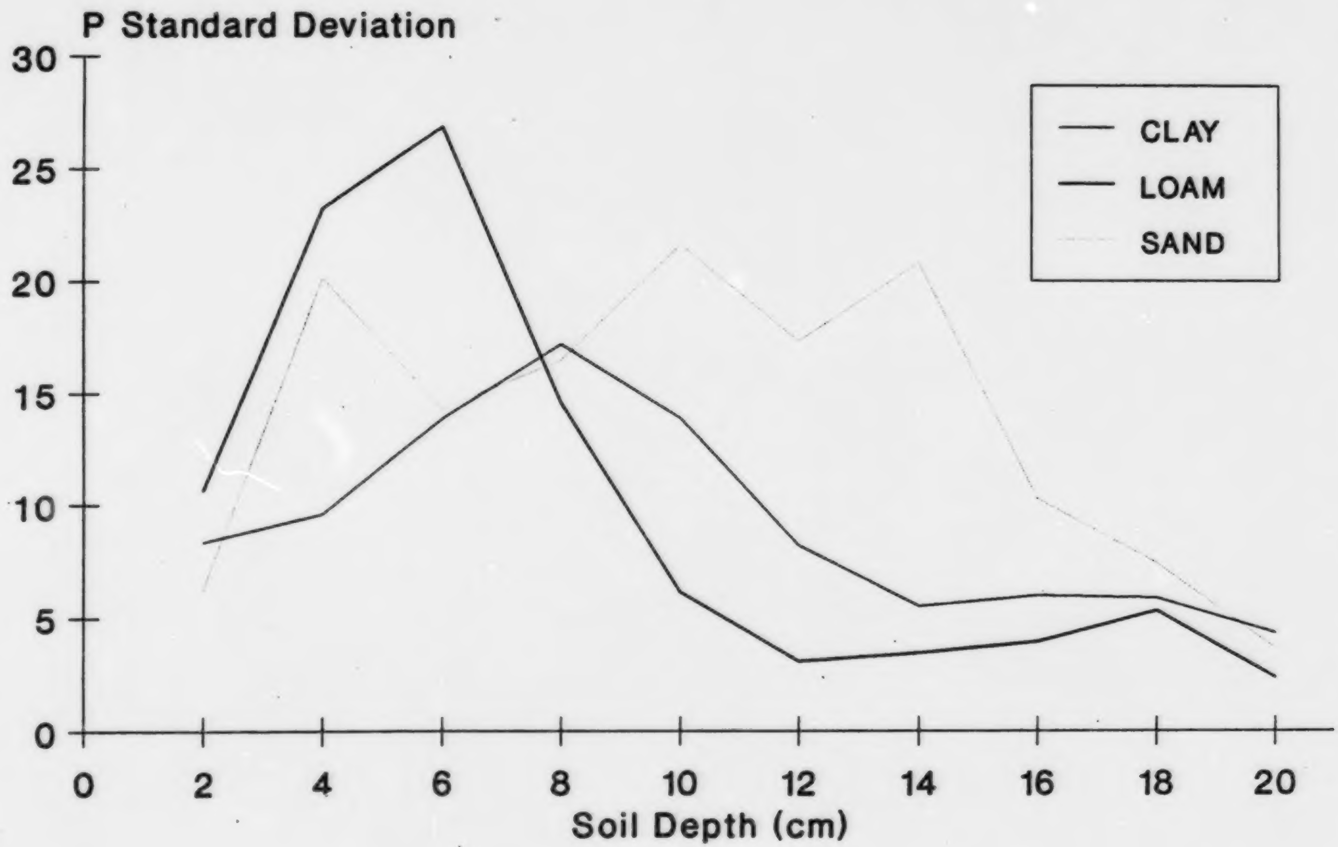
The standard deviation of soil organic matter content among points across a horizontal transect was significantly affected by both soil texture and depth ($p < 0.05$ and $p < 0.01$, respectively). Across all depths, clayey soil showed significantly less horizontal variation in organic matter content then loamy or sandy soils. Across all soil textural classes, the horizontal variation in organic matter was significantly greatest at the 2 cm depth, and significantly least at 18-20 cm.

4.3.4 Soil Nutrient Stratification

4.3.4.1 Phosphorus (P)

Statistical analysis revealed that soil depth was a significant factor ($p < 0.01$) affecting the standard deviation of the concentrations of P across a horizontal transect. Stratification across all soils was significantly greatest between four and ten cm, peaking at the six cm depth (Figure 8.0).

Figure 8.0: Horizontal variation in phosphorus concentrations in soils of different textural classes



Although not statistically significant ($p = 0.11$) soil texture also appeared to affect the horizontal stratification of P. The average standard deviations over all depths within the textural groups showed that clayey and loamy soils had a similar degree of P stratification whereas sandy soils were somewhat more stratified. This may have been a result of the increased standard deviations in sandy soils occurring over a wider range of depths (4 to 16 cm) than in the loamy or clayey soils (6 to 10 cm). This elongated zone of influence in the sandy soils was probably a result of the greater permeability of sands causing leaching of soluble P and, the inability of coarse textured soils to retain P through bonding to colloidal surfaces on soil particles as in the case of clay soils.

The number of years under NT and the horizontal variations in organic matter contents were significant when included in the analysis as covariates ($p < 0.10$ and $p < 0.01$, respectively). Their inclusion, however, did not affect the significance of depth as a factor in the analysis. Of the soil physical property data, only CPR was significantly related to horizontal stratification of P when included in the analysis as a covariate. The inclusion of CPR data in the analysis resulted in the effects of soil texture becoming less significant, indicating a relationship between CPR and soil texture.

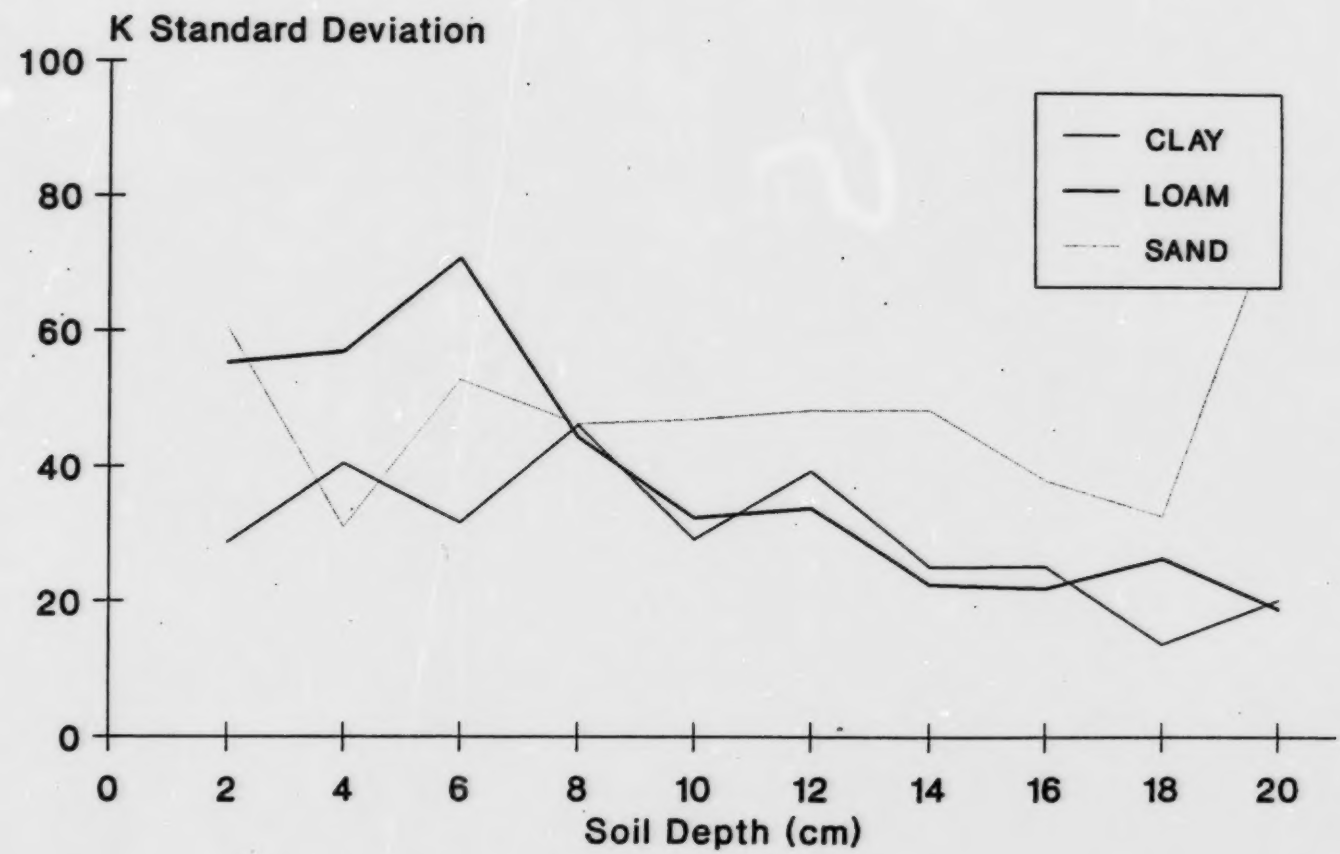
4.3.4.2 Potassium (K)

The standard deviation of the concentrations of K across a horizontal transect in the soil was significantly affected by the soil texture ($p < 0.05$). Horizontal stratification of K was significantly greater in sandy soils than in clayey soils, with loamy soil exhibiting intermediate stratification (Figure 9.0).

Soil sample depth was not a significant factor affecting the horizontal stratification of K.

The number of years under NT was significantly ($p = 0.01$) related to the horizontal stratification of K when included in the analysis as a covariate. Of the soil physical property data, only CPR was significant as a covariate. Neither covariate affected the significance of depth or soil texture as factors determining the horizontal stratification of K.

Figure 9.0: Horizontal variation in potassium concentrations in soils of different textural classes



4.3.4.3 Magnesium (Mg)

The standard deviation of the concentrations of Mg across a horizontal transect in the soil was significantly affected by the soil texture ($p < 0.01$). Horizontal stratification of Mg was significantly greater across all depth in loamy soil than in sandy or clayey soil (Figure 10.0).

Soil sample depth did not significantly affect the horizontal stratification of Mg.

The number of years under NT was not significantly related to the horizontal stratification of Mg when included in the analysis as a covariate. Bulk density and water infiltration rate were both significant factors as covariates ($p < 0.01$), however, neither covariate affected the significance of depth or soil texture as factors determining the horizontal stratification of Mg.

4.3.4.4 Calcium (Ca)

Neither soil texture or sample depth were significant factors affecting the standard deviation of the concentrations of Ca across a horizontal transect in the soil (Figure 11.0).

The number of years under NT and the horizontal variations in pH were significantly related to the horizontal stratification of Ca when included in the analysis as a covariate ($p < 0.10$ in both cases). Cone penetrometer resistance was also significantly related to the horizontal stratification of Ca ($p < 0.10$) and its inclusion in the analysis resulted in texture becoming a significant factor.

Water infiltration rate and soil bulk density were not significantly related to the horizontal stratification of Ca; however, their inclusion in the analysis as a covariate resulted in soil texture becoming a significant factor ($p < 0.05$).

Figure 10.0: Horizontal variation in magnesium concentrations in soils of different textural classes

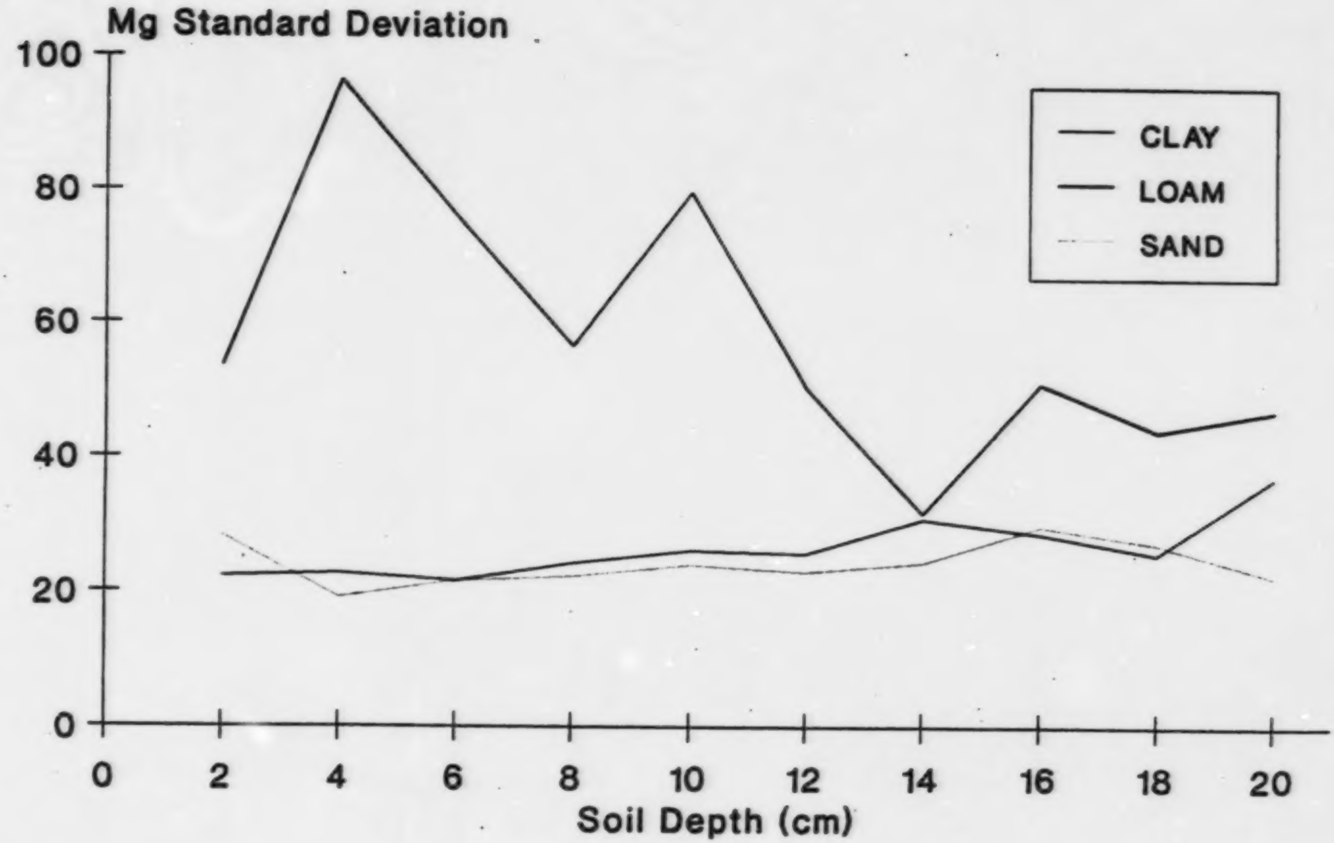
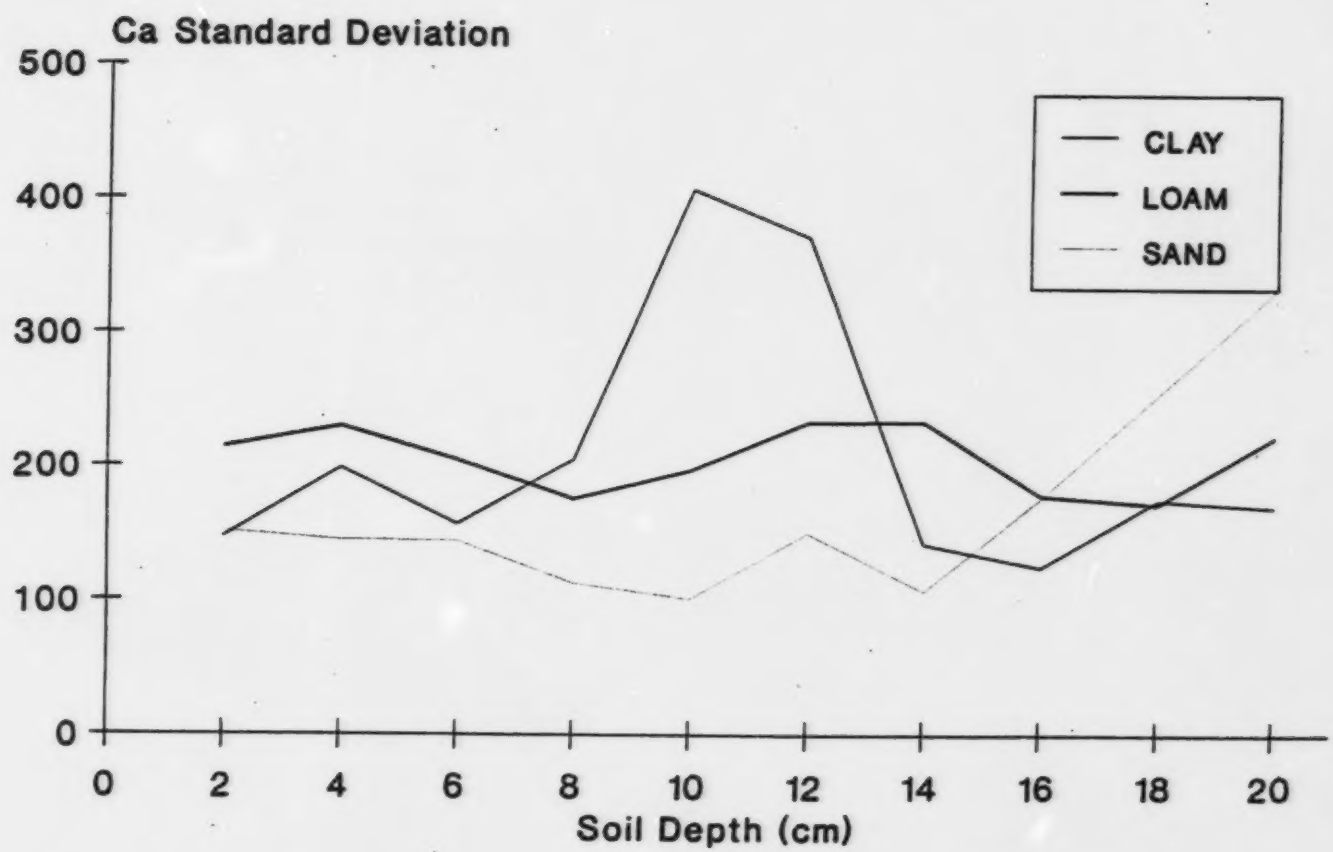


Figure 11.0: Horizontal variation in calcium concentrations in soils of different textural classes



4.4 Summary

The conclusions derived from this study of horizontal stratification of nutrients associated with band application of fertilizers under NT conditions were limited by the data available on field management history. Of the questionnaire data, only the data on number of years that each field had been maintained under NT were sufficiently complete to allow its inclusion in an analysis. This factor was significantly related to the horizontal variation in the concentration of P, K and Ca; the severity of horizontal stratification of nutrients increased with the number of consecutive years under NT.

Soil texture was a significant factor affecting the severity of horizontal stratification of K, Mg and to a lesser extent, P. The exact ranking of the textural classes was inconsistent among the different nutrients; however, the coarse sandy soil generally displayed increased horizontal variation in nutrients over a wider range of soil depth. This was presumably due to the greater permeability of sandy soils and lower nutrient retention through bonding to colloidal surfaces on soil particles.

Horizontal stratification of nutrients generally did not vary greatly with soil depth. Only P stratification was significantly affected by the soil sample depth. The horizontal variation in P concentrations was greatest between 4 and 10 cm, peaking at 6 cm.

5.0 CONCLUSIONS

The degree of mixing of soil associated with different tillage systems had a significant effect upon the distribution of nutrients. Soil under CT practices displayed a relatively even distribution of nutrients within the plough layer as indicated by the slower decline in nutrient concentrations with depth. Soils in fields managed under NT systems had a significantly greater rate of decline in nutrient concentration with soil depth. The lack of soil mixing therefore resulted in an accumulation of nutrients at or near the soil surface.

Although our results were inconclusive, it may be argued that the observed stratification would be cumulative and increase in severity with consecutive years under NT. In the study of horizontal stratification, the number of years under NT was significantly related to the horizontal variation in the concentration of P, K, and Ca. The severity of stratification increased with consecutive years under NT.

Soil texture was a significant factor affecting the stratification of nutrients. Clayey soils have a greater ability to bind P and K at the point at which they are applied. Also, water infiltration and, therefore, leaching of soluble nutrients was greater in sandy soils. Therefore, clayey soils generally displayed an increased vertical stratification, but sandy soils maintained horizontal stratification of nutrients over a wider range of soil depths.

The impact of vertical stratification on nutrient losses to soil erosion was not clear from this study. While conservation tillage resulted in more applied nutrients remaining near the soil surface, it is also known to reduce rates of erosion of the soil surface. The effect of tillage practice on nutrient concentration at the soil surface could not be assessed due to variations in rates of nutrient application and variations in tillage between sites.

Reduced tillage resulted in unevenly distributed nutrient levels, primarily within the soil sampling zone. Vertical stratification of nutrients and the associated accumulation at the soil surface suggests the need for care when sampling soil for nutrient analysis. A shallow sampling depth would lead to an overestimation of the nutrient content of the soil. Conversely, deeper soil sampling in a field operated under an NT system could underestimate the nutrient content and result in over fertilization. This could, in turn, lead to increased nutrient losses by surface erosion and to poorer economic performance.

In light of the above, guidelines should be developed for soil sampling and fertilizer recommendations that would be specific to NT conditions. Fields operated under an RT

system could be sampled and fertilized in the same manner, and at the same rates, as fields maintained under CT.

Horizontal variations in P levels were greatest at the 6 cm depth, indicating that horizontal stratification could also affect the reliability of soil sampling for nutrient analysis. Guidelines for soil sampling in NT fields in which band application of fertilizer is used should also be developed.

It was extremely difficult to locate an adequate number of suitable sites for this study. Fields were required that not only fulfilled the study requirements for tillage, soil type and location, but also for which historical management data were available. In many cases, these data did not exist, or could not be obtained by the researchers. As a result, it seems unrealistic to attempt analyses based on this source of historical management data. Variability in management practices and environmental conditions among the various sites underscored the difficulties in managing such a study under farm field conditions. An assessment of the effects of management practices within conservation tillage systems over time should be carried out under more controlled conditions.

It is concluded that stratification of nutrients in soils does exist, and its severity is primarily related to tillage practice.

6.0 RECOMMENDATIONS FOR FUTURE RESEARCH

This study has identified that nutrient stratification exists under certain conservation tillage systems in Southern Ontario soils. The nature and extent of stratification is highly variable. Because of the difficulties experienced in finding suitable sites under normal field conditions, the effects of specific management practices should be studied under controlled conditions.

REFERENCES

Beauchamp, E.G., MacMillan, K. and Hamilton, H.A. 1976. Extractable phosphorus in surface and subsurface layers of Ste. Rosalie and St. Blaise soil series in Quebec. Can. J. Soil Sci. 56:345-356.

Bullen, C.W., Sopper, R.J. and Bailey, L.D. 1983. Phosphorus nutrition of soybeans as affected by placement of fertilizer phosphorus. Can. J. Soil Sci. 63:199-210.

Burwell, R.E., Schumann, G.E., Heinemann, H.G. and Spooner, R.G. 1987. Nitrogen and phosphorus movement from agricultural watersheds. J. Soil and Water Conserv. 32:226-230.

Dong, A., Simsiman, G.V. and Chesters, G. 1983. Particle size and phosphorus levels in soil, sediment and urban dust and dirt samples from Menomonee River Watershed. Water Research 17:569-577.

Fink, J.R. and Wesley, D. 1974. Corn yield as affected by fertilization and tillage systems. Agron. J. 66:70-71.

Follet, R.F. and Peterson, G.A. 1988. Surface soil nutrient distribution as affected by wheat fallow tillage systems. Soil Sci. Soc. Am. J. 52:141-47.

Hargrove, W.L. 1985. Influence of tillage on nutrient uptake and yield of corn. Agri. J. 77:763-768.

Johnson, H.P., Baker, J.L., Shrader, W.D. and Laflen, M.J. 1979. Tillage system effect on sediments and nutrients in runoff from small watersheds. Am. Soc. Agric. Engs. Trans. 22:1110-1114.

Karlen, D.L., P.G. Hunt and R.B. Campbell. 1984. Crop residue removal effects on corn yield and fertility of a Norfolk sandy loam. Soil Sci. Soc. Amer. J. 48:868-872

Langdale, G.W., Leonard, R.A. and Thomas, A.W. 1985. Conservation practice effects on phosphorus losses from Southern Piedmont watersheds. J. Soil and Water Conserv. 40:157-160.

Lauer, D.A. 1988a. Vertical distribution in soil of unincorporated surface applied phosphorus under sprinkler irrigation. Soil Sci. Soc. Am. J. 52:1685-1692.

Lauer, D.A. 1988b. Vertical distribution of sprinkler applied fertilizer P. Soil Sci. Soc. Am. J. 52:862-868.

MacKeague, J.A. (Editor) 1981. Manual of Soil Sampling and Methods of Analysis. Canadian Society of Soil Science.

MacLean, A.H., Willis, A.L. and Hoffman, D.W. 1971. Distribution of phosphorus fractions within profiles of three Ontario soils. Can. J. Soil Sci. 51:302-304.

Millar, M.H. 1977. Anthropic influences of sediment quality at a source - Nutrients: Carbon, Nitrogen and Phosphorus. Workshop proceedings on fluvial transport of sediments held in Kitchener, Ontario, October 20-22, 1976.

Oloya, T.O. and T.J. Logan. 1980. Phosphate desorption from soils and sediments with varying levels of extractable phosphate. J. Environ. Qual. 9:526-531.

Omanwar, P.K. and Robertson, J.A. 1970. Movement of phosphorus to barley roots growing in soil. Can. J. Soil Sci. 50:57-64.

Peasant, A.R., Dione, J.L. and Genest J. 1987. Soil and nutrient losses in surface runoff from conventional and no till corn systems. Can. J. Soil Sci. 67:835-843.

PLUARG. 1978. Pollution from land use activities. References Group. Environmental management strategy for the Great Lakes system. Final report to the International Joint Commission. Windsor. 113 pp.

Romkins, M.J.M., Nelson, D.W. and Mannering, J.V. 1973. Nitrogen and P composition of surface runoff as affected by tillage method. J. Environ. Qual. 2:292-293.

Rouseau, A., Dickinson, W.T. and Rudra, R.P. 1987. Evaluation of best management practices to control P non-point source pollution. Can. Ag. Eng. 29:163-168.

Sanders, D.H. and Eghball, B. 1988. Effect of phosphorus fertilizer particle size on P fertilizer efficiency. Soil Sci. Soc. Am. J. 52:868-873.

Sharpley, A.N. and Smith 1983. Distribution of phosphorus forms in virgin and cultivated soils and potential erosion losses. Soil Sci. Soc. Am. J. 47:581-586.

Sheard, W. 1980. N and P band for forage establishment Agron. J. 72:89-97.

Spooner, R.G. and Hjelmfelt, A.T. 1985. Concentrated flow erosion and conservation tilled watersheds. Am. Soc. Agr. Engs. Trans. 29:124-127.

Stecker, J.A., Sanders, D.H., Anderson, F.N. and Petterson, G.A. 1988. Phosphorus fertilizer placement and tillage in a wheat fallow cropping sequence. Soil Sci. Soc. Am. J. 52:1063-1068.

Timmons, D.R., Burwell, R.E. and Holt, R.F. 1973. Nitrogen and phosphorus losses in surface runoff from agricultural land as influenced by placement of broadcast fertilizer. Water Res. 9:658-667.

APPENDIX I
EXAMPLE QUESTIONNAIRE ON FIELD MANAGEMENT HISTORY

NUTRIENT DISTRIBUTION & STRATIFICATION RESULTING FROM CONSERVATION FARMING

A QUESTIONNAIRE ON FIELD MANAGEMENT HISTORY

DATE: ______________________

TIME: ______________________

RESPONDENT'S NAME: ______________________

INTERVIEWER'S NAME: ______________________

: by Ecologistics Limited
: for Agriculture Canada

1989

I FARM AND FIELD CHARACTERISTICS

1. FARM CHARACTERISTICS

What kind of farm enterprise are you operating? (Indicate the most important with No.1)

_______ Dairy	_______ Cash crop (specify)
_______ Beef	____________________
_______ Swine	_______ Fruit or vegetable (specify)
_______ Poultry	____________________
_______ Mixed (specify)	_______ Other (specify) _______
____________________	____________________

2. FIELD CHARACTERISTICS

Based on soil survey data and recent field investigations, we have collected the following information on your field(s). If you disagree with us please indicate changes or additions below.

Major Soil Type(s)	Field No. I	Field No. II
1.	____________	____________
2.	____________	____________
3.	____________	____________
4.	____________	____________
Drainage Class	____________	____________
Surface Texture	____________	____________
Landscape Position	____________	____________
Slope	____________	____________

II SOIL CONSERVATION AND OTHER FARM PRACTICES USED ON A REGULAR BASIS

This part of the survey asks questions about 3 groups of practices and how you use them.

A. CROPPING PRACTICES

1. a) What crop rotation have you been using on the field in question?

Crops (in sequence) ________ ________ ________ ________

No. of years in rotation ________ ________ ________ ________

b) For how many years have you used this rotation?

________ No. of years

c) Why do you use this rotation? ________________________________

d) What cropping sequence have you planned for this field in the next four years?

1. ________ 2. ________ 3. ________ 4. ________

e) What other crop rotations have you used in the past on this field?

Crops (in sequence) ________ ________ ________ ________

No. of years in rotation ________ ________ ________ ________

2. a) Do you have a system of crop residue management?

Surface residue ________________________

Residue incorporated in surface soil ________________________

b) For how long have you been practising this system of residue management?

________ No. of years

c) Have you derived any benefits from the use of crop residues?

a) Soil improvement ________________________

b) Moisture content of soil ________________________

c) Crop yields ________________________

3. a) What cover crops, if any, do you plant? (Cover crops include those crops which are killed or tilled under in the spring and those which are harvested the following year i.e. winter wheat)

____

____

____

b) Have you observed any beneficial effects of cover crops on the soils of your field? If yes, please list.

____

____

c) How long have you used cover crops on this field? ________________________

4. Give the record of crop yields on the field as far back as six years, starting with the most recent yield record for 1989, if available.

	Name of Crop	Yield/Acre
1989	__________	__________
1988	__________	__________
1987	__________	__________
1986	__________	__________
1985	__________	__________
1984	__________	__________

B. TILLAGE AND PLANTING PRACTICES

5. Please indicate which tillage practices you have used on this field for the past 3-6 years.

	1989	1988	1987	1986	1985	1984
Crop						
Fall						
Spring						
Inter-row						

6. Please indicate your planting practices.

Seeding rate						
Planter type						
Row spacing						

C. FERTILIZER APPLICATION

7. Please provide information on fertilizer use in this field during the last 3-6 years.

	1989			1988			1987		
Crop	______			______			______		
Fertilizer type	1. ____	2. ____	3. ____	1. ____	2. ____	3. ____	1. ____	2. ____	3.
Analysis	____	____	____	____	____	____	____	____	
Rate	____	____	____	____	____	____	____	____	
Application Method	____	____	____	____	____	____	____	____	
Application Timing	____	____	____	____	____	____	____	____	
If banded: distance from seed	____	____	____	____	____	____	____	____	
depth in soil	____	____	____	____	____	____	____	____	

	1986			1985			1984		
Crop	______			______			______		
Fertilizer type	1. ____	2. ____	3. ____	1. ____	2. ____	3. ____	1. ____	2. ____	3
Analysis	____	____	____	____	____	____	____	____	
Rate	____	____	____	____	____	____	____	____	
Application Method	____	____	____	____	____	____	____	____	
Application Timing	____	____	____	____	____	____	____	____	
If banded: distance from seed	____	____	____	____	____	____	____	____	
depth in soil	____	____	____	____	____	____	____	____	

8. Was lime applied to this field in the last 3-6 years? Yes ____ No ____

If yes, be sure to fill in specifics under question 7.

D. <u>MANURE APPLICATION</u>

9. Have you been applying manure to this field? Yes ____ No ____

If yes, please answer the following questions.

	1989	1988	1987	1986	1985	1984
Animal Source	____	____	____	____	____	____
Type: Liquid	____	____	____	____	____	____
semi-solid	____	____	____	____	____	____
solid	____	____	____	____	____	____
Rate	____	____	____	____	____	____
Time applied: spring	____	____	____	____	____	____
summer	____	____	____	____	____	____
fall	____	____	____	____	____	____
winter	____	____	____	____	____	____
Method of application	____	____	____	____	____	____

E. <u>PESTICIDE APPLICATION</u>

10. Please provide information on pesticide use in this field during the last 3-6 years.

	1989			1988			1987		
Crop									
Product Name	1.	2.	3.	1.	2.	3.	1.	2.	3.
Formulation									
Rate									
Application Method									
Application Timing									

	1986			1985			1984		
Crop									
Product Name	1.	2.	3.	1.	2.	3.	1.	2.	3.
Formulation									
Rate									
Application Method									
Application Timing									

NUTRIENT DISTRIBUTION & STRATIFICATION RESULTING FROM CONSERVATION FARMING

QUESTIONNAIRE CONSENT FORM

The purpose of this questionnaire is to obtain information on the history of conservation farming, particularly on the application of fertilizers. It is our hope that this information will help us understand 'nutrient distribution and stratification' in soils and thereby enhance the development of new technologies that will lead to a reduction in nutrient losses due to soil degradation and improved crop yields.

If there is any information about your experiences that you would not want others to see, please indicate this below at the appropriate section/subsection.

SECTION/SUBSECTION	I am not concerned about confidentiality	I want this information to be confidential
Farm & Field Characteristics		
1. Farm Characteristics	________	________
2. Field Characteristics	________	________
Soil Conservation & Other Practices		
3. Cropping Practices	________	________
	________	________
4. Tillage & Planting Practices	________	________
	________	________
5. Fertilizer Application	________	________
	________	________
	________	________
	________	________
	________	________
6. Manure Application	________	________
	________	________
	________	________
7. Lime Application	________	________
	________	________
	________	________
8. Pesticide Application	________	________
	________	________
	________	________

________________________ ________________

Name Date

APPENDIX II
ANALYSIS OF VARIANCE TABLES - EXPERIMENT I

Analysis of variance for the clay content among the soil textural classes

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
Between groups	3520.6022	2	1760.3011	102.052	.0000
Within groups	569.2200	33	17.2491		
Total (corrected)	4089.8222	35			

0 missing value(s) have been excluded.

Analysis of variance for cone penetrometer resistance in the 0 to 10 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	2414937.5	4	603734.38	5.009	.0063
TILLAGE	1610211.6	2	805105.79	6.680	.0064
TEXTURE	908771.9	2	454385.95	3.770	.0418
2-FACTOR INTERACTIONS	1042137.5	4	260534.37	2.162	.1126
TILLAGE.TEXTURE	1042137.5	4	260534.37	2.162	.1126
RESIDUAL	2289880.0	19	120520.00		
TOTAL (CORR.)	5746955.1	27			

8 missing values have been excluded.

Analysis of Variance for cone penetrometer resistance in the 10 to 20cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	5896865.1	4	1474216.3	7.434	.0009
TILLAGE	2846854.5	2	1423427.2	7.178	.0048
TEXTURE	2587845.4	2	1293922.7	6.525	.0070
2-FACTOR INTERACTIONS	1573049.1	4	393262.28	1.983	.1381
TILLAGE.TEXTURE	1573049.1	4	393262.28	1.983	.1381
RESIDUAL	3767600.8	19	198294.78		
TOTAL (CORR.)	11237515	27			

8 missing values have been excluded.

Analysis of Variance for Cone Penetrometer resistance in the 20 to 45 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	9095163.6	4	2273790.9	8.375	.0005
TILLAGE	761036.4	2	380518.2	1.402	.2705
TEXTURE	8013953.2	2	4006976.6	14.760	.0001
2-FACTOR INTERACTIONS	1106529.9	4	276632.48	1.019	.4226
TILLAGE.TEXTURE	1106529.9	4	276632.48	1.019	.4226
RESIDUAL	5158183.5	19	271483.34		
TOTAL (CORR.)	15359877	27			

8 missing values have been excluded.

Analysis of Variance for soil bulk density

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	.0774189	4	.0193547	2.069	.1252
.TILLAGE	.0629566	2	.0314783	3.365	.0561
.TEXTURE	.0090021	2	.0045011	.481	.6254
2-FACTOR INTERACTIONS	.1527947	4	.0381987	4.083	.0149
TILLAGE.TEXTURE	.1527947	4	.0381987	4.083	.0149
RESIDUAL	.1777626	19	.0093559		
TOTAL (CORR.)	.4079762	27			

8 missing values have been excluded.

Analysis of Variance for water infiltration rates

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	6.0972824	4	1.5243206	3.263	.0353
.TILLAGE	2.7685712	2	1.3842856	2.963	.0772
.TEXTURE	3.4801979	2	1.7400989	3.725	.0443
2-FACTOR INTERACTIONS	2.0218343	4	.5054586	1.082	.3947
TILLAGE.TEXTURE	2.0218343	4	.5054586	1.082	.3947
RESIDUAL	8.4084740	18	.4671374		
TOTAL (CORR.)	16.527591	26			

9 missing values have been excluded.

Multiple range analysis for water infiltration rate by tillage

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
NT	10	.1117795	*
RT	8	.7266190	**
CT	9	.7802128	*

Multiple range analysis for water infiltration rate texture

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
C	9	.1507549	*
S	10	.4398387	**
L	8	1.0246852	*

Analysis of Variance for water infiltration rates with bulk density as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	1.9949442	1	1.9949442	4.475	.0495
BULK DENSITY	1.9949442	1	1.9949442	4.475	.0495
MAIN EFFECTS	5.0995648	4	1.2748912	2.860	.0557
.TILLAGE	1.3954351	2	.6977176	1.565	.2378
.TEXTURE	3.7476521	2	1.8738260	4.203	.0329
2-FACTOR INTERACTIONS	1.8540966	4	.4635242	1.040	.4157
TILLAGE.TEXTURE	1.8540966	4	.4635242	1.040	.4157
RESIDUAL	7.5789851	17	.4458227		
TOTAL (CORR.)	16.527591	26			

9 missing values have been excluded.

Analysis of Variance for Phosphorus stratification

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	24.116183	6	4.0193639	.907	.4939
.STRATUM	12.633017	2	6.3165083	1.425	.2459
.TILLAGE	5.666017	2	2.8330083	.639	.5302
.TEXTURE	5.817150	2	2.9085750	.656	.5213
2-FACTOR INTERACTIONS	76.553967	12	6.379497	1.439	.1634
STRATUM.TILLAGE	56.085117	4	14.021279	3.163	.0176
STRATUM.TEXTURE	12.708467	4	3.177117	.717	.5827
TILLAGE.TEXTURE	7.760383	4	1.940096	.438	.7811
RESIDUAL	394.50925	89	4.4326882		
TOTAL (CORR.)	495.17940	107			

0 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 0 to 10 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	48.133611	4	12.033403	2.629	.0564
.TILLAGE	35.421806	2	17.710903	3.869	.0333
.TEXTURE	12.711806	2	6.355903	1.388	.2667
2-FACTOR INTERACTIONS	11.491944	4	2.8729861	.628	.6470
TILLAGE.TEXTURE	11.491944	4	2.8729861	.628	.6470
RESIDUAL	123.60250	27	4.5778704		
TOTAL (CORR.)	183.22806	35			

0 missing values have been excluded.

Multiple range analysis for Phosphorus stratification in the 0 to 10 cm soil depth range by tillage

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
NT	12	-2.6833333	*
RT	12	-1.9208333	**
CT	12	-.3041667	*

Analysis of Variance for Phosphorus stratification in the 0 to 10 cm soil depth range with cone penetrometer resistance as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	12.395875	1	12.395875	3.278	.0869
CPR	12.395875	1	12.395875	3.278	.0869
MAIN EFFECTS	56.171861	4	14.042965	3.714	.0225
.TILLAGE	42.491893	2	21.245947	5.619	.0127
.TEXTURE	26.118319	2	13.059159	3.454	.0538
2-FACTOR INTERACTIONS	13.714131	4	3.4285329	.907	.4809
TILLAGE.TEXTURE	13.714131	4	3.4285329	.907	.4809
RESIDUAL	68.061258	18	3.7811810		
TOTAL (CORR.)	150.34313	27			

8 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 0 to 10 cm soil depth range with bulk density as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	15.148474	1	15.148474	4.002	.0608
BULK DENSITY	15.148474	1	15.148474	4.002	.0608
MAIN EFFECTS	56.966549	4	14.241637	3.763	.0215
.TILLAGE	30.997099	2	15.498549	4.095	.0342
.TEXTURE	27.424433	2	13.712217	3.623	.0476
2-FACTOR INTERACTIONS	10.098893	4	2.5247232	.667	.6231
TILLAGE.TEXTURE	10.098893	4	2.5247232	.667	.6231
RESIDUAL	68.129209	18	3.7849561		
TOTAL (CORR.)	150.34313	27			

8 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 0 to 10 cm soil depth range with water infiltration rate (GPI) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	5.5798840	1	5.5798840	1.478	.2406
.GPI	5.5798840	1	5.5798840	1.478	.2406
MAIN EFFECTS	60.600825	4	15.150206	4.014	.0180
.TILLAGE	37.651171	2	18.825585	4.988	.0197
.TEXTURE	30.572347	2	15.286174	4.050	.0364
2-FACTOR INTERACTIONS	10.900600	4	2.7251499	.722	.5887
TILLAGE TEXTURE	10.900600	4	2.7251499	.722	.5887
RESIDUAL	64.160358	17	3.7741387		
TOTAL (CORR.)	141.24167	26			

9 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 0 to 10 cm soil depth range with Ca concentrationas a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	41.601373	1	41.601373	11.036	.0027
.CA	41.601373	1	41.601373	11.036	.0027
MAIN EFFECTS	34.967847	4	8.741962	2.319	.0837
.TILLAGE	34.577016	2	17.288508	4.586	.0197
.TEXTURE	.406533	2	.203267	.054	.9476
2-FACTOR INTERACTIONS	8.6475500	4	2.1618875	.573	.6843
TILLAGE.TEXTURE	8.6475500	4	2.1618875	.573	.6843
RESIDUAL	98.011285	26	3.7696648		
TOTAL (CORR.)	183.22806	35			

0 missing values have been excluded.

Analysis of Variance for Phosphorus stratification with pH as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	.4992155	1	.4992155	.111	.7428
.PH	.4992155	1	.4992155	.111	.7428
MAIN EFFECTS	23.848029	6	3.9746715	.887	.5078
.TILLAGE	5.782971	2	2.8914855	.646	.5268
.TEXTURE	5.174406	2	2.5872031	.578	.5633
.STRATUM	12.718599	2	6.3592997	1.420	.2473
2-FACTOR INTERACTIONS	76.671927	12	6.389327	1.426	.1691
TILLAGE.TEXTURE	10.205149	5	2.041030	.456	.8081
TILLAGE.STRATUM	58.954913	5	11.790983	2.632	.0289
TEXTURE.STRATUM	12.306253	4	3.076563	.687	.6029
RESIDUAL	394.16023	88	4.4790935		
TOTAL (CORR.)	495.17940	107			

0 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 0 to 10 cm soil depth range with organic matter gradient as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	14.454780	1	14.454780	3.053	.0924
.OM	14.454780	1	14.454780	3.053	.0924
MAIN EFFECTS	33.939794	4	8.484949	1.792	.1607
.TILLAGE	20.300173	2	10.150086	2.144	.1374
.TEXTURE	12.842125	2	6.421063	1.356	.2752
2-FACTOR INTERACTIONS	11.748082	4	2.9370205	.620	.6520
TILLAGE.TEXTURE	11.748082	4	2.9370205	.620	.6520
RESIDUAL	123.08540	26	4.7340538		
TOTAL (CORR.)	183.22806	35			

0 missing values have been excluded.

Analysis of Variance for organic matter stratification in the 0 to 10 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	.0230778	4	.0057694	4.562	.0061
.TILLAGE	.0229847	2	.0114924	9.088	.0010
.TEXTURE	.0000931	2	.0000465	.037	.9639
2-FACTOR INTERACTIONS	.0032028	4	8.00694E-004	.633	.6432
TILLAGE.TEXTURE	.0032028	4	8.00694E-004	.633	.6432
RESIDUAL	.0341438	27	.0012646		
TOTAL (CORR.)	.0604243	35			

0 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 10 to 20 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	11.553611	4	2.8884028	.620	.6519
.TILLAGE	10.362639	2	5.1813194	1.113	.3433
.TEXTURE	1.190972	2	.5954861	.128	.8805
2-FACTOR INTERACTIONS	12.151944	4	3.0379861	.652	.6302
TILLAGE.TEXTURE	12.151944	4	3.0379861	.652	.6302
RESIDUAL	125.73188	27	4.6567361		
TOTAL (CORR.)	149.43743	35			

0 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 10 to 20 cm soil depth range with bulk density as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	14.399414	1	14.399414	4.725	.0433
BULK DENSITY	14.399414	1	14.399414	4.725	.0433
MAIN EFFECTS	14.302264	4	3.5755660	1.173	.3556
.TILLAGE	11.137166	2	5.5685831	1.827	.1894
.TEXTURE	3.704822	2	1.8524111	.608	.5553
2-FACTOR INTERACTIONS	5.9222520	4	1.4805630	.486	.7460
TILLAGE.TEXTURE	5.9222520	4	1.4805630	.486	.7460
RESIDUAL	54.850356	18	3.0472420		
TOTAL (CORR.)	89.474286	27			

8 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 10 to 20 cm soil depth range with water infiltration rate (GPI) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	15.495319	1	15.495319	5.119	.0370
.GPI	15.495319	1	15.495319	5.119	.0370
MAIN EFFECTS	11.246592	4	2.8116480	.929	.4704
.TILLAGE	8.430575	2	4.2152874	1.393	.2754
.TEXTURE	2.396834	2	1.1984172	.396	.6791
2-FACTOR INTERACTIONS	9.4848393	4	2.3712098	.783	.5515
TILLAGE.TEXTURE	9.4848393	4	2.3712098	.783	.5515
RESIDUAL	51.456212	17	3.0268360		
TOTAL (CORR.)	87.682983	26			

9 missing values have been excluded.

Analysis of Variance for Phosphorus stratification in the 20 to 45cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	20.589528	4	5.1473819	1.347	.2784
.TILLAGE	15.966689	2	7.9833444	2.089	.1434
.TEXTURE	4.622839	2	2.3114194	.605	.5535
2-FACTOR INTERACTIONS	26.089344	4	6.5223361	1.706	.1777
TILLAGE.TEXTURE	26.089344	4	6.5223361	1.706	.1777
RESIDUAL	103.20203	27	3.8222972		
TOTAL (CORR.)	149.88090	35			

0 missing values have been excluded.

Analysis of Variance for Potassium stratification

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	891.72472	6	148.62079	3.884	.0017
.STRATUM	654.81588	2	327.40794	8.557	.0004
.TILLAGE	228.90574	2	114.45287	2.991	.0553
.TEXTURE	8.00310	2	4.00155	.105	.9008
2-FACTOR INTERACTIONS	893.52903	12	74.46075	1.946	.0391
STRATUM.TILLAGE	690.45106	4	172.61277	4.511	.0023
STRATUM.TEXTURE	117.57454	4	29.39363	.768	.5487
TILLAGE.TEXTURE	85.50343	4	21.37586	.559	.6932
RESIDUAL	3405.4587	89	38.263581		
TOTAL (CORR.)	5190.7125	107			

0 missing values have been excluded.

Analysis of Variance for Potassium stratification in the 0 to 10 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	731.50417	4	182.87604	2.673	.0534
.TILLAGE	698.45042	2	349.22521	5.105	.0132
.TEXTURE	33.05375	2	16.52688	.242	.7871
2-FACTOR INTERACTIONS	284.37833	4	71.094583	1.039	.4053
TILLAGE.TEXTURE	284.37833	4	71.094583	1.039	.4053
RESIDUAL	1847.0725	27	68.410093		
TOTAL (CORR.)	2862.9550	35			

0 missing values have been excluded.

Multiple range analysis for Potassium stratification in the 0 to 10 cm soil depth range by tillage

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
RT	12	-11.329167	*
NT	12	-11.300000	*
CT	12	-1.970833	*

Analysis of Variance for Potassiu : stratification in the 0 to 10 cm soil depth range with cone penetrometer resistance as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	438.53136	1	438.53136	6.703	.0185
CPR	438.53136	1	438.53136	6.703	.0185
MAIN EFFECTS	560.23555	4	140.05889	2.141	.1175
.TILLAGE	311.49647	2	155.74823	2.380	.1210
.TEXTURE	175.24095	2	87.62048	1.339	.2869
2-FACTOR INTERACTIONS	467.71047	4	116.92762	1.787	.1754
TILLAGE.TEXTURE	467.71047	4	116.92762	1.787	.1754
RESIDUAL	1177.6876	18	65.427089		
TOTAL (CORR.)	2644.1650	27			

8 missing values have been excluded.

Analysis of Variance for Potassium stratification in the 10 to 20 cm soildepth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	124.64278	4	31.160694	1.541	.2185
.TILLAGE	104.03014	2	52.015069	2.573	.0949
.TEXTURE	20.61264	2	10.306319	.510	.6063
2-FACTOR INTERACTIONS	18.219444	4	4.5548611	.225	.9219
TILLAGE.TEXTURE	18.219444	4	4.5548611	.225	.9219
RESIDUAL	545.90750	27	20.218796		
TOTAL (CORR.)	688.76972	35			

0 missing values have been excluded.

Analysis of Variance for Potassium stratification in the 10 to 20 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	125.51615	3	41.83872	5.434	.0121
.COVER	102.29920	1	102.29920	13.287	.0030
.TILLAGE	19.72743	2	9.86371	1.281	.3106
2-FACTOR INTERACTIONS	14.334539	2	7.1672693	.931	.4189
COVER.TILLAGE	14.334539	2	7.1672693	.931	.4189
RESIDUAL	100.08720	13	7.6990156		
TOTAL (CORR.)	239.93789	18			

17 missing values have been excluded.

Multiple range analysis for Potassium stratification in the 10 to 20 cm soil depth range by cover

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
NO	12	-5.5416667	*
YES	7	-.6500000	*

Analysis of Variance for Potassium stratification in the 20 to 45 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	188.78750	4	47.196875	2.112	.1069
.TILLAGE	116.87625	2	58.438125	2.615	.0916
.TEXTURE	71.91125	2	35.955625	1.609	.2187
2-FACTOR INTERACTIONS	192.08625	4	48.021563	2.149	.1021
TILLAGE.TEXTURE	192.08625	4	48.021563	2.149	.1021
RESIDUAL	603.29813	27	22.344375		
TOTAL (CORR.)	984.17188	35			

0 missing values have been excluded.

Multiple range analysis for Potassium stratification in the 20 to 45 cm soil depth range by tillage

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
CT	12	-6.2291667	*
RT	12	-3.0416667	**
NT	12	-1.9916667	*

Analysis of Variance for Potassium stratification in the 20 to 45 cm soil depth range with cone penetrometer resistance as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	149.06653	1	149.06653	7.078	.0159
CPR	149.06653	1	149.06653	7.078	.0159
MAIN EFFECTS	182.17679	4	45.544198	2.162	.1147
.TILLAGE	55.86985	2	27.934923	1.326	.2902
.TEXTURE	111.05568	2	55.527838	2.637	.0990
2-FACTOR INTERACTIONS	231.55449	4	57.888622	2.749	.0604
TILLAGE.TEXTURE	231.55449	4	57.888622	2.749	.0604
RESIDUAL	379.09746	18	21.060970		
TOTAL (CORR.)	941.89527	27			

8 missing values have been excluded.

Analysis of Variance for Magnesium stratification

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	1054.9406	6	175.82343	2.829	.0144
.STRATUM	5.7238	2	2.86188	.046	.9550
.TILLAGE	490.5839	2	245.29194	3.947	.0228
.TEXTURE	558.6329	2	279.31646	4.495	.0138
2-FACTOR INTERACTIONS	905.02264	12	75.41855	1.214	.2865
STRATUM.TILLAGE	91.51028	4	22.87757	.368	.8307
STRATUM.TEXTURE	470.63750	4	117.65938	1.893	.1186
TILLAGE.TEXTURE	342.87486	4	85.71872	1.379	.2475
RESIDUAL	5530.8191	89	62.144035		
TOTAL (CORR.)	7490.7823	107			

0 missing values have been excluded.

Multiple range analysis for Magnesium stratification by tillage

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
NT	36	-3.8652778	*
RT	36	.6236111	*
CT	36	.6875000	*

Multiple range analysis for Magnesium stratification by texture

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
S	36	-3.6458333	*
L	36	-.8333333	**
C	36	1.9250000	*

Analysis of Variance for Magnesium stratification in the 0 to 10 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	164.60361	4	41.150903	1.790	.1599
.TILLAGE	73.12764	2	36.563819	1.591	.2223
.TEXTURE	91.47597	2	45.737986	1.990	.1562
2-FACTOR INTERACTIONS	75.412778	4	18.853194	.820	.5236
TILLAGE.TEXTURE	75.412778	4	18.853194	.820	.5236
RESIDUAL	620.54500	27	22.983148		
TOTAL (CORR.)	860.56139	35			

0 missing values have been excluded.

Analysis of Variance for Magnesium stratification in the 0 to 10 cm soil depth range with cone penetrometer resistance as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	26.405196	1	26.405196	1.266	.2753
CPR	26.405196	1	26.405196	1.266	.2753
MAIN EFFECTS	220.44426	4	55.111065	2.642	.0677
.TILLAGE	54.24707	2	27.123533	1.300	.2968
.TEXTURE	126.09778	2	63.048892	3.023	.0738
2-FACTOR INTERACTIONS	123.21268	4	30.803169	1.477	.2506
TILLAGE.TEXTURE	123.21268	4	30.803169	1.477	.2506
RESIDUAL	375.44528	18	20.858071		
TOTAL (CORR.)	745.50741	27			

8 missing values have been excluded.

Analysis of Variance for Magnesium stratification in the 0 to 10 cm soil depth range with bulk density as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	8.2857268	1	8.2857268	.373	.5552
BULK DENSITY	8.2857268	1	8.2857268	.373	.5552
MAIN EFFECTS	267.78708	4	66.94677	3.017	.0455
.TILLAGE	59.65748	2	29.82874	1.344	.2857
.TEXTURE	203.38387	2	101.69194	4.583	.0246
2-FACTOR INTERACTIONS	70.010800	4	17.502700	.789	.5475
TILLAGE.TEXTURE	70.010800	4	17.502700	.789	.5475
RESIDUAL	399.42381	18	22.190211		
TOTAL (CORR.)	745.50741	27			

8 missing values have been excluded.

Analysis of Variance for Magnesium stratification in the 0 to 10 cm soil depth range with water infiltration rate (GPI) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	1.9544712	1	1.9544712	.084	.7791
GPI	1.9544712	1	1.9544712	.084	.7791
MAIN EFFECTS	190.89311	4	47.723278	2.040	.1341
.TILLAGE	25.91479	2	12.957396	.554	.5847
.TEXTURE	142.52133	2	71.260667	3.047	.0740
2-FACTOR INTERACTIONS	131.64238	4	32.910595	1.407	.2739
TILLAGE.TEXTURE	131.64238	4	32.910595	1.407	.2739
RESIDUAL	397.60170	17	23.388336		
TOTAL (CORR.)	722.09167	26			

9 missing values have been excluded.

Analysis of Variance for Magnesium stratification in the 0 to 10 cm soil depth range with organic matter gradient as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	79.326377	1	79.326377	3.451	.0746
OM	79.326377	1	79.326377	3.451	.0746
MAIN EFFECTS	108.46854	4	27.117134	1.180	.3428
.TILLAGE	22.21688	2	11.108442	.483	.6222
.TEXTURE	87.65736	2	43.828682	1.907	.1688
2-FACTOR INTERACTIONS	75.128132	4	18.782033	.817	.5259
TILLAGE.TEXTURE	75.128132	4	18.782033	.817	.5259
RESIDUAL	597.63834	26	22.986090		
TOTAL (CORR.)	860.56139	35			

0 missing values have been excluded.

Analysis of Variance for Magnesium stratification in the 10 to 20 cm soil depth range

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	307.86611	4	76.96653	2.970	.0373
.TILLAGE	92.41556	2	46.20778	1.783	.1874
.TEXTURE	215.45056	2	107.72528	4.157	.0267
2-FACTOR INTERACTIONS	32.028194	4	8.0070486	.309	.8694
TILLAGE.TEXTURE	32.028194	4	8.0070486	.309	.8694
RESIDUAL	699.70875	27	25.915139		
TOTAL (CORR.)	1039.6031	35			

0 missing values have been excluded.

Analysis of Variance for Magnesium stratification in the 20 to 45 cm soil depth range with cone penetrometer resistance as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	157.40452	1	157.40452	1.137	.3005
CPR	157.40452	1	157.40452	1.137	.3005
MAIN EFFECTS	1958.9988	4	489.74970	3.536	.0269
.TILLAGE	489.3221	2	244.66105	1.767	.1993
.TEXTURE	1385.0929	2	692.54645	5.000	.0187
2-FACTOR INTERACTIONS	804.90745	4	201.22686	1.453	.2576
TILLAGE.TEXTURE	804.90745	4	201.22686	1.453	.2576
RESIDUAL	2492.9192	18	138.49551		
TOTAL (CORR.)	5414.2300	27			

8 missing values have been excluded.

Analysis of Variance for Calcium concentration

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	68351403	6	11391900	5.739	.0000
.STRATUM	656590	2	328295	.165	.3478
.TILLAGE	761128	2	380564	.192	.8259
.TEXTURE	66933685	2	33466842	16.860	.0000
2-FACTOR INTERACTIONS	22534253	12	1877854.4	.946	.5058
STRATUM.TILLAGE	1321799	4	330449.7	.166	.9549
STRATUM.TEXTURE	109881	4	27470.1	.014	.9996
TILLAGE.TEXTURE	21102574	4	5275643.5	2.658	.0379
RESIDUAL	1.7667E0008	89	1985007.2		
TOTAL (CORR.)	2.6755E0008	107			

0 missing values have been excluded.

Multiple range analysis for ORGANIC MATTER STRATIFICATION IN THE 0 TO 10 CM SOIL DEPTH RANGE by tillage

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
NT	12	-.0475000	*
RT	12	-.0120833	*
CT	12	.0141667	*

APPENDIX III
ANALYSIS OF VARIANCE TABLES - EXPERIMENT II

Analysis of Variance for the horizontal stratification of phosohorus

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	2526.2270	11	229.65700	2.915	.0028
.DEPTH	2161.9214	9	240.21349	3.049	.0045
.TEXTURE	364.3056	2	182.15280	2.312	.1078
2-FACTOR INTERACTIONS	1603.2482	18	89.069344	1.131	.3474
DEPTH.TEXTURE	1603.2482	18	89.069344	1.131	.3474
RESIDUAL	4726.9908	60	78.783160		
TOTAL (CORR.)	8856.4660	89			

0 missing values have been excluded.

Analysis of variance for clay content among the soil textural classes

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
Between groups	893.76000	2	446.88000	78.538	.0000
Within groups	34.14000	6	5.69000		
Total (corrected)	927.90000	8			

0 missing value(s) have been excluded.

Multiple range analysis for the horizontal stratification of phosphorus by depth

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
20	9	3.471177	*
18	9	6.248226	**
16	9	6.772185	**
2	9	8.419654	***
12	9	9.564114	****
14	9	9.946553	****
10	9	13.903884	****
8	9	16.103242	***
4	9	17.675842	**
6	9	18.363852	*

years under no till as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	301.13924	1	301.13924	3.460	.0704
YEARS.NOTILL	301.13924	1	301.13924	3.460	.0704
MAIN EFFECTS	2798.1152	11	254.37411	2.923	.0056
.DEPTH	2562.5991	9	284.73323	3.271	.0047
.TEXTURE	235.5161	2	117.75807	1.353	.2703
2-FACTOR INTERACTIONS	1637.2594	18	90.958853	1.045	.4371
DEPTH	1637.2594	18	90.958853	1.045	.4371
RESIDUAL	3394.4808	39	87.037968		
TOTAL (CORR.)	8130.9946	69			

20 missing values have been excluded.

Analysis of Variance for the horizontal stratification of phosphorus with organic matter stratification as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	696.22463	1	696.22463	9.008	.0039
ORGANIC MATTER	696.22463	1	696.22463	9.008	.0039
MAIN EFFECTS	2323.8922	11	211.26293	2.733	.0064
.DEPTH	2074.0022	9	230.44469	2.982	.0054
.TEXTURE	218.8009	2	109.40044	1.415	.2509
2-FACTOR INTERACTIONS	1276.3326	18	70.907364	.917	.5616
DEPTH.TEXTURE	1276.3326	18	70.907364	.917	.5616
RESIDUAL	560.0166	59	77.288417		
TOTAL (CORR.)	8856.4660	89			

0 missing values have been excluded.

Analysis of Variance for the horizontal stratification of phosphorus with cone penetrometer resistance (CPR) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	952.59781	1	952.59781	11.415	.0014
CPR	952.59781	1	952.59781	11.415	.0014
MAIN EFFECTS	1827.9732	11	166.17938	1.991	.0499
.DEPTH	1552.9279	9	172.54754	2.068	.0311
.TEXTURE	209.7762	2	104.88811	1.257	.2935
2-FACTOR INTERACTIONS	1610.9236	18	89.495753	1.072	.4054
DEPTH.TEXTURE	1610.9236	18	89.495753	1.072	.4054
RESIDUAL	4088.9995	49	83.448969		
TOTAL (CORR.)	8480.4940	79			

10 missing values have been excluded.

Analysis of Variance for the horizontal stratification of potassium

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	11312.764	11	1028.4331	1.406	.1939
.DEPTH	6221.596	9	691.2885	.945	.4937
.TEXTURE	5091.168	2	2545.5838	3.480	.0371
2-FACTOR INTERACTIONS	10040.471	18	557.80394	.763	.7329
DEPTH.TEXTURE	10040.471	18	557.80394	.763	.7329
RESIDUAL	43883.388	60	731.38980		
TOTAL (CORR.)	65236.623	89			

0 missing values have been excluded.

Multiple range analysis for the horizontal stratification of Potassium by texture

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
Clay	30	30.030298	*
Loam	30	38.404885	**
Sand	30	48.428788	*

Analysis of Variance for the horizontal stratification of Potassium with number of years under notill as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	3185.5826	1	3185.5826	3.438	.0713
YEARS NO TILL	3185.5826	1	3185.5826	3.438	.0713
MAIN EFFECTS	8140.3714	11	740.0338	.799	.6405
.DEPTH	6133.2688	9	681.4743	.735	.6742
.TEXTURE	2007.1026	2	1003.5513	1.083	.3485
2-FACTOR INTERACTIONS	9035.4886	18	501.97159	.542	.9184
DEPTH.TEXTURE	9035.4886	18	501.97159	.542	.9184
RESIDUAL	36137.667	39	926.60684		
TOTAL (CORR.)	56499.109	69			

20 missing values have been excluded.

Analysis of Variance for the horizontal stratification of potassium with cone penetrometer resistance (CPR) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	4976.8098	1	4976.8098	7.045	.0107
CPR	4976.8098	1	4976.8098	7.045	.0107
MAIN EFFECTS	10286.060	11	935.0964	1.324	.2403
.DEPTH	3806.698	9	422.9665	.599	.7918
.TEXTURE	6021.654	2	3010.8270	4.262	.0197
2-FACTOR INTERACTIONS	12153.931	18	675.21838	.956	.5216
DEPTH.TEXTURE	12153.931	18	675.21838	.956	.5216
RESIDUAL	34616.394	49	706.45702		
TOTAL (CORR.)	62033.195	79			

10 missing values have been excluded.

Analysis of Variance for the horizontal stratification of magnesium

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	24405.285	11	2218.662	4.146	.0002
.DEPTH	2198.629	9	244.292	.457	.8977
.TEXTURE	22206.656	2	11103.328	20.748	.0000
2-FACTOR INTERACTIONS	8941.2985	18	496.73880	.928	.5496
DEPTH.TEXTURE	8941.2985	18	496.73880	.928	.5496
RESIDUAL	32108.395	60	535.13992		
TOTAL (CORR.)	65454.978	89			

0 missing values have been excluded.

Multiple range analysis for the horizontal stratification of magnesium by texture

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
S	30	24.175253	*
C	30	26.457006	*
L	30	58.579142	*

Analysis of Variance for the horizontal stratification of magnesium with water infiltration rate (GPI) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	7564.9505	1	7564.9505	16.550	.0002
GPI.	7564.9505	1	7564.9505	16.550	.0002
MAIN EFFECTS	18694.067	11	1699.4607	3.718	.0007
.DEPTH	2285.373	9	253.9303	.556	.8262
.TEXTURE	16408.695	2	8204.3474	17.949	.0000
2-FACTOR INTERACTIONS	9163.6794	18	509.09330	1.114	.3682
DEPTH.TEXTURE	9163.6794	18	509.09330	1.114	.3682
RESIDUAL	22397.788	49	457.09772		
TOTAL (CORR.)	57820.486	79			

10 missing values have been excluded.

Analysis of Variance for the horizontal stratification of magnesium with bulk density as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	24405.285	11	2218.662	4.146	.0002
.DEPTH	2198.629	9	244.292	.457	.8977
.TEXTURE	22206.656	2	11103.328	20.748	.0000
2-FACTOR INTERACTIONS	8941.2985	18	496.73880	.928	.5496
DEPTH.TEXTURE	8941.2985	18	496.73880	.928	.5496
RESIDUAL	32108.395	60	535.13992		
TOTAL (CORR.)	65454.978	89			

0 missing values have been excluded.

Analysis of Variance for the horizontal stratification of calcium

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	137264.56	11	12478.596	.609	.8142
.DEPTH	104700.38	9	11633.376	.567	.8183
.TEXTURE	32564.18	2	16282.089	.794	.4567
2-FACTOR INTERACTIONS	313209.76	18	17400.542	.849	.6382
DEPTH. TEXTURE	313209.76	18	17400.542	.849	.6382
RESIDUAL	1230186.1	60	20503.102		
TOTAL (CORR.)	1680660.5	89			

0 missing values have been excluded.

Analysis of Variance for the horizontal stratification of calcium with the number of years under no till as covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	98939.968	1	98939.968	10.896	.0021
YEARS NO TILL	98939.968	1	98939.968	10.896	.0021
MAIN EFFECTS	98669.649	11	8969.968	.988	.4738
.DEPTH	72549.593	9	8061.066	.888	.5446
.TEXTURE	26120.056	2	13060.028	1.438	.2497
2-FACTOR INTERACTIONS	94596.415	18	5255.3564	.579	.8934
DEPTH.TEXTURE	94596.415	18	5255.3564	.579	.8934
RESIDUAL	354147.70	39	9080.7102		
TOTAL (CORR.)	646353.73	69			

20 missing values have been excluded.

Analysis of Variance for the horizontal stratification of calcium with pH stratification as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	74753.188	1	74753.188	3.702	.0592
pH	74753.188	1	74753.188	3.702	.0592
MAIN EFFECTS	130333.24	11	11848.476	.587	.8320
.DEPTH	128223.64	9	14247.071	.706	.7013
.TEXTURE	459.01	2	229.505	.011	.9887
2-FACTOR INTERACTIONS	284202.80	18	15789.044	.782	.7119
DEPTH.TEXTURE	284202.80	18	15789.044	.782	.7119
RESIDUAL	1191371.2	59	20192.733		
TOTAL (CORR.)	1680660.5	89			

0 missing values have been excluded.

Analysis of Variance for the horizontal stratification of calcium with cone penetrometer resistance as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	33181.530	1	33181.530	3.777	.0577
CPR	33181.530	1	33181.530	3.777	.0577
MAIN EFFECTS	93957.073	11	8541.552	.972	.4835
.DEPTH	53760.589	9	5973.399	.680	.7231
.TEXTURE	44031.485	2	22015.742	2.506	.0920
2-FACTOR INTERACTIONS	113319.24	18	6295.5132	.717	.7778
DEPTH.TEXTURE	113319.24	18	6295.5132	.717	.7778
RESIDUAL	430469.35	49	8785.0887		
TOTAL (CORR.)	670927.19	79			

10 missing values have been excluded.

Analysis of Variance for the horizontal stratification of calcium with water infiltration rate (GPI) as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	19561.995	1	19561.995	2.343	.1323
GPI	561.995	1	19561.995	2.343	.1323
MAIN EFFECTS	129424.66	11	11765.878	1.409	.1990
.DEPTH	60910.47	9	6767.830	.811	.6088
.TEXTURE	68514.19	2	34257.097	4.103	.0225
2-FACTOR INTERACTIONS	112790.11	18	6266.1175	.750	.7432
DEPTH.TEXTURE	112790.11	18	6266.1175	.750	.7432
RESIDUAL	409150.41	49	8350.0085		
TOTAL (CORR.)	670927.19	79			

10 missing values have been excluded.

Analysis of Variance for the horizontal stratification of calcium with bulk density as a covariate

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
COVARIATES	23448.563	1	23448.563	2.786	.1015
CPN	23448.563	1	23448.563	2.786	.1015
MAIN EFFECTS	122235.83	11	11112.349	1.320	.2421
.DEPTH	60910.47	9	6767.830	.804	.6145
.TEXTURE	61325.36	2	30662.682	3.643	.0335
2-FACTOR INTERACTIONS	112790.11	18	6266.1175	.744	.7495
DEPTH.TEXTURE	112790.11	18	6266.1175	.744	.7495
RESIDUAL	412452.67	49	8417.4015		
TOTAL (CORR.)	670927.19	79			

10 missing values have been excluded.

Analysis of Variance for the horizontal stratification of pH

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	.4136031	11	.0376003	2.675	.0073
.DEPTH	.0416755	9	.0046306	.329	.9619
.TEXTURE	.3719276	2	.1859638	13.231	.0000
2-FACTOR INTERACTIONS	.0990641	18	.0055036	.392	.9849
DEPTH.TEXTURE	.0990641	18	.0055036	.392	.9849
RESIDUAL	.8432948	60	.0140549		
TOTAL (CORR.)	1.3559620	89			

0 missing values have been excluded.

Multiple range analysis for the horizontal stratification of pH by texture

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups	
Clay	30	.1187891	*	
Loam	30	.1460347	*	
Sand	30	.2667236		*

Analysis of Variance for the horizontal stratification of organic matter

Source of variation	Sum of Squares	d.f.	Mean square	F-ratio	Sig. level
MAIN EFFECTS	1.0561796	11	.0960163	11.102	.0000
.DEPTH	9783095	9	.1087011	12.568	.0000
.TEXTURE	.0778701	2	.0389351	4.502	.0151
2-FACTOR INTERACTIONS	.2070271	18	.0115015	1.330	.2029
DEPTH.TEXTURE	.2070271	18	.0115015	1.330	.2029
RESIDUAL	.5189283	60	.0086488		
TOTAL (CORR.)	1.7821350	89			

0 missing values have been excluded.

Multiple range analysis for the horizontal stratification of organic matter by texture

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups	
Clay	30	.1218159	*	
Loam	30	.1795992		*
Sand	30	.1879812		*

Multiple range analysis for the horizontal stratification of organic matter by depth

Method: 95 Percent LSD Intervals

Level	Count	Average	Homogeneous Groups
18	9	.0000000	*
20	9	.0000000	*
10	9	.1191400	*
8	9	.1365899	*
12	9	.1622202	**
6	9	.1623334	**
14	9	.1995226	**
4	9	.2466756	*
16	9	.2488947	*
2	9	.3559445	*